CANADIAN JOURNAL OF AGRICULTURAL SCIENCE

(*formerly* Scientific Agriculture)

VOLUME 35 JANUARY-FEBRUARY 1955 No. 1

THE EFFECTS OF IRRIGATION AND CHEMICAL FERTILIZATION ON THE YIELD AND PROTEIN CONTENT OF A PASTURE MIXTURE[1]

W. L. PELTON AND L. R. WEBBER[2]

Department of Soils, Ontario Agricultural College, Guelph, Ont.

[Received for publication July 20, 1954]

ABSTRACT

One year's data from irrigating an Orchard Grass-Ladino Clover mixture in the Guelph area indicate that supplemental water and chemical fertilizer are important in maintaining pasture yields. The last two clippings, four and five, the only ones to be irrigated, gave highly significant increases in dry matter and protein production. Fertilizer increased total production of dry matter and protein and significantly added to the protein content of grass. At each level of fertility, irrigation increased the legume content of the forage whereas fertilizer increased the proportion of grass in the mixture at each level of watering.

INTRODUCTION

Irrigation is the mechanical application of water to soil in order to supplement rainfall and supply moisture at times and in quantities essential for maximum plant growth. Long established in arid regions, irrigation is becoming increasingly important in the humid-temperate areas as assurance against crop failure due to drought. This form of assurance is becoming a necessity against the short but frequent periods of drought during comparatively short growing seasons.

In the past, the use of irrigation in Ontario has been confined chiefly to cash crops. However, by maintaining or increasing the yield of pasture, the use of irrigation may enable the farmer to increase the livestock carrying-capacity of a given acreage. Conversely, it may allow him to reduce the required pasture acreage for a given number of animals, and to use this extra land for additional grain or cash crops.

The purpose of the research reported herein was to study the effects of water and fertilizer on the dry matter and protein production of an Orchard Grass-Ladino Clover pasture.

LITERATURE REVIEW

Drought Frequency

The rainfall at Guelph for the past 44 years has averaged 16.37 inches during the months April to September, inclusive. The water requirement

[1] Adapted for publication from a thesis submitted to the Graduate School, University of Toronto, by W. L. Pelton, in partial fulfilment of the requirements for the degree of Master of Science in Agriculture.

[2] Lecturer and Associate Professor, respectively.

TABLE 1.—THE MOISTURE DEFICIENCIES FOR SELECTED PERIODS AT GUELPH THAT MAY BE EXPECTED ONCE IN THE INDICATED NUMBER OF YEARS

Moisture deficiency (inches)	Selected periods				
	June	July	Aug.	Sept.	April-Sept. incl.
0	1.3	2.5	5.1	4.4	15.5
0– 2	7.8	3.1	2.0	1.6	4.4
2– 4	—	6.2	2.8	6.2	3.9
4– 6	—	15.2	—	—	2.8
6– 8	—	—	—	—	10.0
8–10	—	—	—	—	15.5

The frequency is based on the period 1923-1953, inclusive.

of crops in the Guelph area has been estimated at about 23 inches (6), over half of which may be needed in the summer months of June, July, and August. A review of precipitation records for the past 31 years reveals that there has been a moisture deficiency at Guelph in all but two years and that these deficiencies have been as much as 9.22 inches.

The deficiencies shown in Table 1 were calculated following the method of Thornthwaite (6). A deficiency of 2 to 4 inches has not been observed at Guelph during June but did occur five times in July to give an expectancy of once every 6.2 years. A similar deficiency occurred more frequently in August or once in every 2.8 years.

During the growing season the most frequent deficiency was 4 to 6 inches and occurred once every 2.8 years.

Irrigation and Fertilization

Various studies (1, 2, 3, 4, 5, 11) indicate that irrigation and fertilization significantly increase the production of dry matter and protein of pasture mixtures. Reports (3, 4, 5, 11) also indicate an increase in clover dry matter due to irrigation, and an increase in grass dry matter due to fertilizer.

The only studies of pasture irrigation in Ontario were carried out by Appleton and Wynd (1). They have reported substantial increases in dry matter yield due to separate applications of supplemental water and fertilizer as well as considerably greater increases from the combined use of irrigation and fertilization.

Determination of Water Requirements

The daily evapo-transpiration, and subsequently the soil moisture status, can be calculated mathematically according to Thornthwaite (9).

Harvesting Methods

Wagner and associates (10) found that the strip method of obtaining pasture yields gave results which more closely compare with those obtained by animal grazing methods than did the cage plot method. Sprague and

Garber (8) investigated harvesting methods from the standpoint of time and height of clipping for maximum yield and recovery of pasture plants. They concluded that the most satisfactory results were obtained by clipping the forage when it had attained a height of approximately 8 inches, and that suitable recovery was made when a 2-inch stubble was left.

MATERIALS AND EXPERIMENTAL METHODS

Plot Characteristics

The pasture irrigation experiment was established on a three-year old sod, predominantly Orchard Grass and Ladino Clover, on a Guelph loam soil at the Ontario Agricultural College farm. Because the plot area was fairly level, it was assumed that no irrigation water or natural precipitation was lost through run-off. The fertility level of the surface soil was low according to the rapid soil test by the Soils Department, Ontario Agricultural College.

The experimental area was laid out in a modified split plot design. Five replications were used, each of which was split longitudinally for the purpose of maintaining two levels of fertility. The replications were then split laterally to accommodate four levels of watering, which were randomized within each replication. Individual plots measured 20 feet by 20 feet.

Irrigation Methods

Water was supplied by a College main and applied to the plots through perforated pipe.

Bulk density and field capacity determinations were made for the top two feet of soil, and from these data the storage capacity of the 24-inch profile was calculated to be 6.57 inches of water. Evapo-transpiration values were subtracted from the soil moisture content and a daily record of the soil moisture status was plotted graphically for each of the four levels of watering.

For this experiment, the objective was to maintain four levels of watering as follows:

0—No irrigation. Replenishment due to natural precipitation.
1—Replenishment due to natural precipitation plus irrigation, with a maximum allowable deficit of 4 inches below field capacity.
2—Replenishment due to natural precipitation plus irrigation, with a maximum allowable deficit of 3 inches below field capacity.
3—Replenishment due to natural precipitation plus irrigation, with a maximum allowable deficit of 2 inches below field capacity.

These four levels of watering will be referred to later as water levels 0, 1, 2, and 3.

Fertilization

Before establishing the plots, the entire area had been fertilized with 550 lb. per acre of 4-12-10 fertilizer on April 14. This was the only fertilizer the low fertility plots received. During the summer soil samples were taken every two weeks for an N-P-K analysis. On the basis of the soil analysis the high fertility plots received the following applications:

June 1—1,000 lb. per acre 5-10-20
July 20—1,000 lb. per acre 0-12-20
150 lb. per acre ammonium nitrate.

Harvesting and Analyses

The plots were clipped when the forage on the watered areas attained a height of about 8 inches. A swath 2.5 feet by 15 feet was cut through the centre of each plot, and a sample set aside for moisture determinations. Another sample was separated into grass, legumes, and weeds. Each component was dried, and weighed, after which the per cent composition of the mixture was calculated.

A modified Kjeldahl analysis (7) was done to determine the total nitrogen content of the forage, and from this value the crude protein was calculated.

DISCUSSION OF RESULTS

Water Application

The rainfall during the spring of 1953 kept the soil moisture content near the field capacity value until late in June. The monthly distribution of rainfall is listed in Table 2.

The evapo-transpiration values were tabulated daily, and along with rainfall records the soil moisture status was calculated. An example of this tabulation appears in Table 3 for the period of August 16-25, inclusive, on a single level of watering.

TABLE 2.—RAINFALL IN INCHES FOR THE MONTHS OF APRIL TO SEPTEMBER, INCLUSIVE

Period	April	May	June	July	Aug.	Sept.	Total
1953	2.21	7.39	3.63	2.74	2.41	2.23	20.61
44-year average	2.38	2.72	2.84	3.07	2.86	2.50	16.37

TABLE 3.—TABULATED CALCULATION OF SOIL MOISTURE STATUS ON WATER LEVEL 3, FOR THE PERIOD AUGUST 16-25, INCLUSIVE

Date	Rainfall	Evapo-transpiration	Irrigation	Soil moisture
	(in.)	(in.)	(in.)	(in.)
Aug. 16	0.01	0.14	—	5.22
Aug. 17-20 (incl.)	0.00	0.45	—	4.77
Aug. 21	0.03	0.14	—	4.66
Aug. 22	0.00	0.14	0.83	5.35
Aug. 23-24 (incl.)	0.00	0.30	—	5.05
Aug. 25	0.16	0.15	—	5.06

TABLE 4.—DATES AND AMOUNTS OF IRRIGATION FOR FOUR LEVELS OF WATERING

Date	Amount of water applied according to levels (in.)			
	0	1	2	3
July 19	—	0.31	0.63	1.25
31	—	—	—	0.63
Aug. 22	—	0.83	0.83	0.83
27	—	—	0.83	0.83
Sept. 2	—	1.00	1.00	1.00
4	—	—	—	1.00
Totals	0	2.14	3.29	5.54

The maximum allowable deficit for water level 3 was 2 inches below field capacity, or a moisture status of 4.57 inches. On August 21, there were 4.66 inches of water in the 24-inch profile. Evapo-transpiration for the next 24 hours brought the level to 4.52 inches, at which time supplemental water was applied.

Similar data were used to plot graphs of the soil moisture status for each of the four levels of watering. Graphs for the period of July 5 to September 10, inclusive, are found in Figure 1.

On some plots the soil moisture status, Figure 1, was below the maximum allowable deficit for a particular level of watering because windy conditions delayed the application of supplemental water. This was perhaps the greatest limitation to the use of perforated pipe for small-plot irrigation. The method of determining water use is a mathematical manipulation of weather data, and remains one of several such methods requiring further investigation.

Dry Matter and Protein

During the season the plots were clipped five times; only the fourth and fifth clippings received supplemental water. As a result of considerable rainfall in May and June, the moisture supply in the soil was plentiful prior to the third clipping in July, Table 5.

One of the objectives of this project was to measure the yield response of an Orchard Grass-Ladino Clover pasture mixture at four levels of watering, and at low and high levels of fertility. The dry matter produced per clipping for each of the above treatments appears in Table 6.

It is evident, from Table 6, that on the low fertility plots there was a general decrease in production per clip, except in the case of the third clipping. It is possible that clipping two was low because of the 7.19 inches of rain (Table 5) which could have caused poor soil aeration and retarded growth. For the fourth and fifth clippings, which received supplemental water, there is an apparent increase in dry matter yield with water.

TABLE 5.—DATES OF CLIPPING, GROWTH PERIODS, RAINFALL, AND AMOUNT OF SUPPLEMENTAL WATER (IN.) FOR FIVE CLIPPINGS

Clipping	Date	Growth period	Rain	Levels of watering			
				0	1	2	3
		(days)	(in.)				
First	May 19	19+	2.61	—	—	—	—
Second	June 17	28	7.19	—	—	—	—
Third	July 13	25	2.32	—	—	—	—
Fourth	Aug. 10	27	3.86	0	0.31	0.63	1.88
Fifth	Sept. 9	29	0.84	0	1.83	2.66	3.66
Totals			16.82	0	2.14	3.29	5.54
Number of irrigations			—	0	3	4	6

TABLE 6.—DRY MATTER PRODUCED (LB./AC.) PER CLIPPING AT FOUR LEVELS OF WATERING. EACH VALUE IS A MEAN OF FIVE REPLICATIONS

Clipping	Level of watering			
	0	1	2	3
	Low Fertility			
First	1023	997	1016	1151
Second	792	755	829	676
Third	832	815	922	862
Fourth	656	745	835	808
Fifth	193	383	518	596
	High Fertility			
First	1023	997	1016	1151
Second	1063	895	745	863
Third	1352	1102	1238	1200
Fourth	1341	1170	1212	1379
Fifth	560	997	1171	1104

On the high fertility plots fertilizer was applied soon after the first clipping, and perhaps accounts for the increase in production of these plots over the low fertility plots. Here again the growth may have been reduced by excess moisture. Another application of fertilizer before the fourth

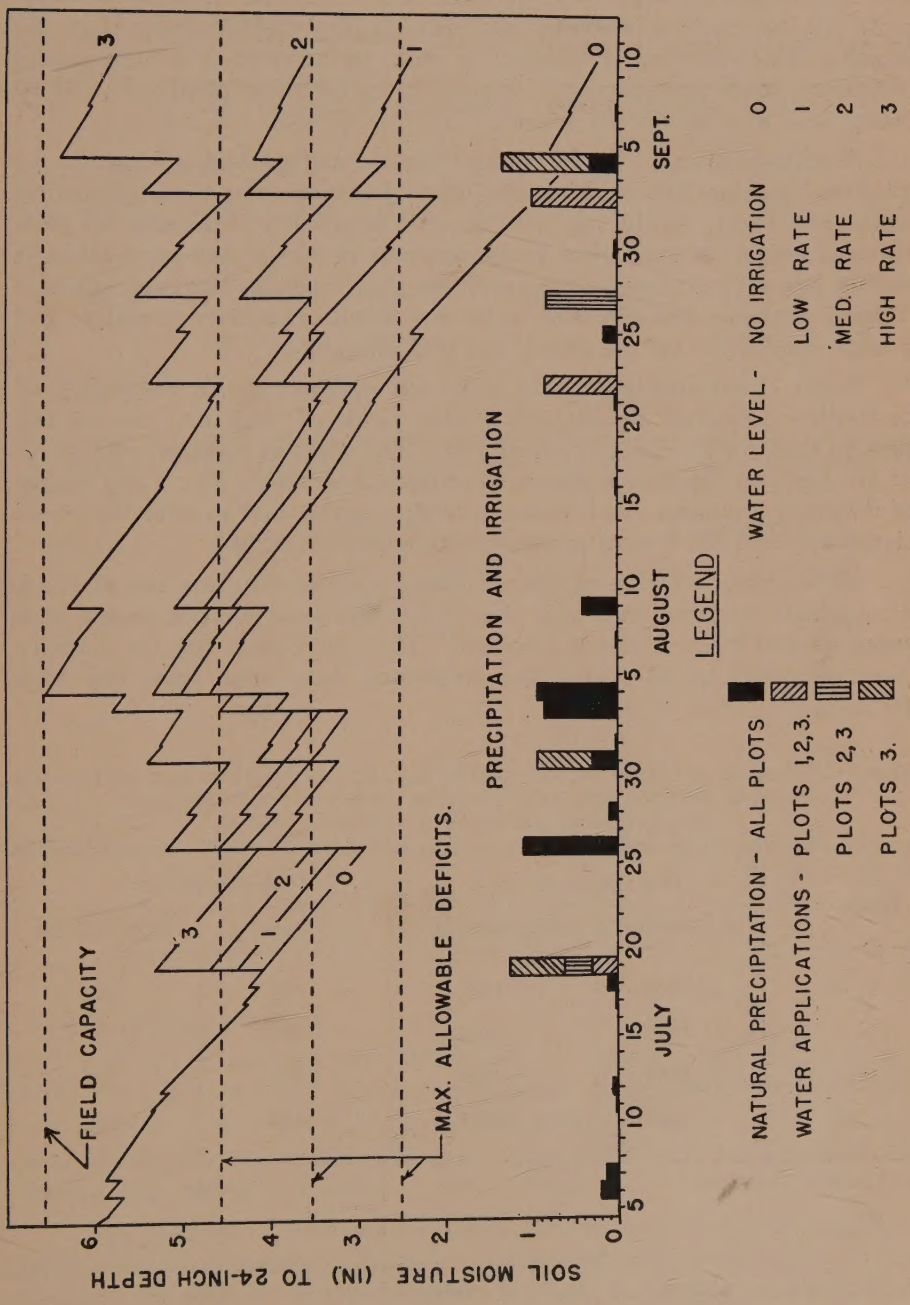

FIGURE 1. Moisture status of plots at four levels of watering.

clipping, along with the water applications, sustained the yields of the fourth clipping. The rainfall on the fifth clipping, Table 5, was 0.84 inches and this moisture deficiency is reflected in the low yields from the 0 water plot. At all levels of watering the fifth clipping yielded lower than the fourth. This decrease in production may be attributed to a moisture deficiency, inadequate fertility, or a tendency for these plants to produce less growth with advancing season.

A statistical analysis of dry matter yield and protein production for all five clippings indicated no significant increases due to supplemental water, but highly significant increases due to fertility. Because no plots received irrigation until after three clippings of forage had been taken it seemed advisable to analyse separately the data from the last two clippings. Table 7 compares the effects of water and fertilizer on the dry matter and protein production for the fourth and fifth clippings.

Table 7 indicates that at the same soil moisture status the high level of fertility produced significantly better yields of both dry matter and protein than the low fertility treatment. The effect of supplemental water on the last two clippings is also evident from this table. The 2 and 3 rates of watering produced yield increases of dry matter and protein that were significant over the 0 water plots at both levels of fertility.

There exists a highly significant linear response to water but the lack of quadratic response indicated that the maximum yield obtainable with supplemental water was not attained. The yields from the low fertility plots appeared to be nearer the maximum than those from the high fertility.

TABLE 7.—THE MEAN VALUES OF DRY MATTER (LB./AC.) AND PROTEIN (LB./AC.) OF THE PASTURE MIXTURE ACCORDING TO FOUR LEVELS OF WATERING, AND TWO LEVELS OF FERTILITY (CLIPPINGS 4 AND 5)

Water levels	Dry matter (lb./ac.)		Protein (lb./ac.)	
	Low fertility	High fertility	Low fertility	High fertility
0	849	1899	198	443
1	1128	2206	264	536
2	1354	2405	325	542
3	1404	2521	340	586
L.S.D. water treatment	(0.05)	304	(82)	
	(0.01)	427	(116)	
L.S.D. fertility treatment	(0.05)	113	(33)	
	(0.01)	219	(55)	

TABLE 8.—THE MEAN VALUES OF PERCENTAGE PROTEIN IN GRASS AND LEGUMES, ACCORDING TO FOUR LEVELS OF WATERING AND TWO LEVELS OF FERTILITY (CLIPPINGS 4 AND 5)

	Levels of watering							
	0		1		2		3	
	Grass	Legume	Grass	Legume	Grass	Legume	Grass	Legume
Low fertility	18.45	25.69	19.05	25.40	20.01	25.45	20.08	26.52
High fertility	21.19	26.00	22.42	26.12	22.48	24.58	22.95	24.92

L.S.D. water	(0.05)	N.S.	L.S.D. fertility	(0.05)	1.14%
	(0.01)	N.S.		(0.01)	1.89%

TABLE 9.—THE MEAN VALUES OF DRY MATTER (LB./AC.) OF GRASS AND OF LEGUME ACCORDING TO FOUR LEVELS OF WATERING AND TWO LEVELS OF FERTILITY (CLIPPING 5)

Water level	Low fertility		High fertility	
	Grass	Legume	Grass	Legume
0	79.2	114.2	238.0	321.8
1	101.6	281.2	311.4	685.4
2	147.2	371.2	451.0	720.2
3	197.2	399.2	437.6	667.8

L.S.D. water (0.05) = 85.0 lb. per ac. Fertilizer (0.05) = 56.3 lb./ac.
(0.01) = 119.3 lb. per ac. (0.01) = 93.1 lb./ac.
Separates (0.05) = 86.3 lb./ac.
(0.01) = 116.0 lb./ac.

Protein Content of Species

The protein content was determined on the grass and on the legume from the fourth and fifth clippings combined. The purpose of these determinations was to investigate the possible effects of water and fertilizer on the protein content of the individual species. The mean values of five replications appear in Table 8.

The addition of fertilizer increased the protein content of grass by a highly significant amount, Table 8. Increasing amounts of water tended to raise the protein content of grass, but not significantly. No definite trend is evident in the protein content of the legume as a result of the application of water or fertilizer.

Relative Production of Grass and Legume

The relative production of grass and legume in a pasture mixture changes during the course of a season. These changes may be brought about by species' characteristics, grazing or clipping, and climatic effects. It was apparent during this experiment that water and fertilizer had an effect on the relative production of grass and legumes that would be expressed in the fifth clipping. Table 9 compares the production of grass and legumes for the last clipping on September 9.

It is evident from Table 9 that water consistently increased the yields of grass and legumes and that there is a highly significant difference between the amounts of grass and of legumes produced, except in the case of the 0 water treatment. All levels of irrigation increased legume production over the 0 water treatment while fertilizer significantly increased the production of grass and legumes at each level of watering.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Department of Agricultural Engineering, Ontario Agricultural College, for making the irrigation equipment available.

REFERENCES

1. Appleton, J. M., and F. L. Wynd. A preliminary study of the application of the percentage yield concept to the response of forage crops to irrigation water. Sci. Agr. 31 : 139-147. 1951.
2. Kidder, E. H., and J. R. Davis. Supplemental irrigation on sandy soils in Michigan. Agr. Eng. 34 : 765. 1953.
3. Levine, G., and H. E. Gray. Pasture irrigation research. Progress report of one year's results. N.Y.State College of Agriculture. Mimeo. Bull. A-9. 1952.
4. McKibben, G. E., L. E. Card, C. A. VanDoren, and R. F. Fullerman. Soil moisture availability in irrigated and nonirrigated areas. Agr. J. 42 : 565-570. 1950.
5. Robinson, R. R., and V. G. Sprague. Responses of orchard grass-ladino clover to irrigation and nitrogen fertilization. Agr. J. 44 : 244-247. 1952.
6. Sanderson, M. Moisture relationships in southern Ontario. Sci. Agr. 30 : 235-255. 1950.
7. Soble, A. E., H. Yaska, and J. Cohen. A convenient method of determining small amounts of ammonia and other bases by the use of boric acid. J. of Biol. Chem. 118 : 443. 1937.
8. Sprague, V. G., and R. J. Garber. Effect of time and height of cutting and nitrogen fertilization on the persistence of the legume, and production of on orchard grass-ladino mixture. Agr. J. 42 : 586-593. 1950.
9. Thornthwaite, C. W. An approach toward a rational classification of climate. Geog. Rev. 38 : 55-95. 1948.
10. Wagner, R. E., M. A. Hein, J. B. Shepherd, and R. E. Ely. A comparison of cage and mower strip methods with grazing results in determining production of dairy pastures. Agr. J. 42 : 487-491. 1950.
11. Whitaker, R. W., and W. F. Lytle. Supplemental irrigation of pasture. Agr. Eng. 32 : 163-165. 1951.

THE RELATIONSHIP OF SOIL PHOSPHORUS TESTS TO CROP YIELD AND TO THE REQUIREMENT OF THE TOMATO FOR PHOSPHATIC FERTILIZER[1]

H. B. Heeney,[2] R. F. Bishop[3] and H. Hill[4]

Canada Department of Agriculture, Ottawa

[Received for publication July 29, 1954]

ABSTRACT

Field and laboratory investigations relative to the production of canning tomatoes in Prince Edward County, Ontario, were conducted during a four-year period. The study, designed to establish correlation tables between phosphorus soil test values and crop response to phosphatic fertilizer, included soils of varying texture and reaction.

Bray's method for adsorbed and easily acid soluble phosphorus as well as one employing a 1 per cent solution of K_2CO_3 as extractant were used to obtain estimates of available soil phosphorus. Yields from plots receiving no phosphorus were expressed as a percentage of those from plots receiving phosphorus. Adequate amounts of nitrogen and potassium were applied in all cases.

The percentage yields plotted against the soil test values resulted in a curvilinear relationship similar to that for the Law of Diminishing Returns. This provided a basis for predicting the percentage yield to be expected for various soil test values. Of the two chemical procedures used Bray's gave the most consistent results. This method showed that a soil test value of approximately 250 pounds per acre of phosphorus (P) may be expected to give 90 per cent of the maximum yield. Preliminary results relative to the amount of phosphatic fertilizer required to give maximum yield for various soil test values are presented.

INTRODUCTION

In the production of vegetable canning crops a satisfactory basis for making fertilizer recommendations is of major importance. This is due to the fact that relatively large applications of commercial fertilizers are used, orthodox grassland rotations are generally not feasible due to the high price of the land involved, and fertilizer requirements vary because of natural soil differences, management practices, and the nature of the crops grown.

Although current and past research indicates soil analysis to be the logical tool for fertility diagnosis, the use of soil test values as a basis for fertilizer recommendations has too often proved unsatisfactory. It is submitted that failure to correlate soil test values with yield response is largely responsible. In many instances the present use of soil analysis has the weakness of inadequate or complete lack of data to ensure correct interpretations since the validity of various chemical methods has frequently been determined in the laboratory without the benefit of suitable field experiments.

Possibly the most satisfactory approach to the problem of efficient estimation of crop fertilizer requirement is found in the work of Bray (2,3,4) and Bray and Dickman (5) in which plant response is the measure

[1] Joint contribution from the Horticulture Division, Experimental Farms Service, and the Chemistry Division, Science Service. Scientific Contribution No. 830 Horticulture Division, and Scientific Contribution No. 258 Chemistry Division.

[2] Junior Horticulturist, Horticulture Division.

[3] Chemist, Chemistry Division.

[4] Principal Horticulturist, Horticulture Division.

of effectiveness. Bray has shown satisfactory correlations between soil tests for phosphorus and potassium and crop response to these nutrients added as fertilizer. He used a modified interpretation of Mitscherlich's Law of Diminishing Returns (7) in which the Mitscherlich constant was not accepted, but was replaced with an experimentally developed constant applicable only to a given crop and locality. This work was followed by that of Arnold and Schmidt (1) in which promising results with tomatoes were reported. The results of 4 years' trials with these techniques in respect to the production of canning tomatoes in Prince Edward County, Ontario, are presented in this paper.

MATERIALS AND METHODS

The soils of Prince Edward County have a textural range from light sands to heavy clays and although the majority are neutral or alkaline in reaction some are moderately acid (8). The field trials were located on growers' properties where tomatoes were grown on a commercial basis. Since the canning industry is of major importance in Prince Edward County most farmers grow some tomatoes. Thus it was possible to locate experimental plots on soils which varied considerably in texture and reaction, and which had been subjected to variable management practices and fertilizer treatments.

As pointed out by Bray (4) a study designed to establish correlations between soil tests and crop response must be divided into two phases: (*1*) The correlation of phosphorus soil test values with the percentage sufficiency of soil phosphorus; and (*2*) The determination of the fertilizer required to give maximum yield for each soil test value. The current investigation deals primarily with the first phase.

The mathematical approach to the first phase of the study, as outlined by Bray (4), is based on the fact that, when the percentage yields from different fields are plotted against the corresponding soil test values for phosphorus, the resulting curve closely coincides with that for the Law of Diminishing Returns. The similarity suggests that the relationship might be expressed by a modification of the basic Mitscherlich equation (7.) The modified equation adopted by Bray was:

$$\text{Log } (A-y) = \text{Log } A - c_1 b_1,$$

where A represented the yield of a plot treated so that all nutrients were adequate or in slight excess, y represented the yield of a plot treated with adequate amounts of all the nutrients except the one under study, b_1 was the soil test value of the y plot, and c_1 was the proportionality constant. In the above equation A was considered to be 100 per cent and y was expressed as a percentage of A. This tended to eliminate differences due to variety, management and seasonal effects.

In the second phase of the study, where a relationship is shown between the soil test value and the fertilizer requirement, a more complex equation was used to permit a mathematical evaluation of the relationship. This equation, a modification of the one used in the first phase of the study, is as follows:

$$\text{Log } (A-y) = \text{Log } A - (c_1 b_1 + cx),$$

where c_1 has already been calculated, c is a second proportionality constant, and x is the increment of fertilizer added as pounds of P_2O_5 per acre.

Two field plot designs were used in this investigation. In one a complete plot (NPK) was adjacent to a plot (NK) receiving no phosphatic fertilizers. In the other, the NK plot was surrounded by four plots which received increasing increments of phosphatic fertilizer as well as amounts of nitrogen and potash considered to be adequate or in slight excess. Fertilizers were applied in the form of ammonium sulphate, superphosphate, and muriate of potash. The amounts used provided, on an acre basis, 60 lb. of N, 240-360 lb. of P_2O_5, and 200-300 lb. of K_2O. In using these quantities the inference is made that yields would not be increased by additional nitrogenous, phosphatic or potassic fertilizers.

The average plot size was 0.012 acres although this varied as some growers used a 4 x 4 foot plant spacing while others employed a 6 x 3 foot spacing. The fertilizers were broadcast and disked in ten days before planting. Planting was the responsibility of the grower who was requested to omit the use of a high phosphorus starter solution in the experimental plots. The grower was also responsible for cultivation as well as disease and insect control.

Yield records, taken from 18-21 plants per plot, depending on the spacing used by the grower, included all fruits that reached marketable maturity by the first frost. Yields were taken at approximately weekly intervals.

Soil samples were taken prior to the application of the fertilizer and estimates of available phosphorus were obtained by Bray's method for acid soluble plus adsorbed phosphorus (4) as well as by extraction with a 1 per cent K_2CO_3 solution as outlined by Hockensmith *et al.* (6).

RESULTS AND DISCUSSION

Relationships Between Soil Test Values and Per Cent Yield

From 1950 to 1953 inclusive there were 50 comparisons of NPK with NK plots. Each comparison was replicated two or more times and the yields averaged.

The soil test values as determined by two methods, the yield on the NK plots expressed as a percentage of the yield on the NPK plots, and the calculated c_1 values for the 50 comparisons, are presented in Table 1. The data are presented by years and arranged in order of increasing soil test values as obtained by Bray's method. Although considerable variability exists, the data indicate that as the soil test value increased the omission of phosphatic fertilizer had a decreasing effect on yield.

The percentage yields plotted against the soil test values obtained by Bray's method and by using a 1 per cent K_2CO_3 solution as extractant are presented in Figures 1 and 2 respectively. The data plotted in this way indicate a curvilinear relationship between the percentage yields and the soil test values, a result paralleling that reported by other investigators (1,4).

The data in Figures 1 and 2 indicate that there is less variation in the results obtained by the Bray method than in those obtained when a K_2CO_3

TABLE 1.—SOIL TEST VALUES, PERCENTAGE YIELDS AND c_1 VALUES FOR 50 FIELD TRIALS

Year and trial no.		Soil test values (lb./ac. P)		Percentage yield*	c_1 values	
		Bray	K_2CO_3		Bray	K_2CO_3
1950	1	93	128	51.0	0.00333	0.00242
	2	109	152	77.1	0.00587	0.00421
	3	119	217	78.2	0.00556	0.00305
	4	123	195	76.9	0.00517	0.00326
	5	144	376	87.5	0.00627	0.00240
	6	175	375	82.5	0.00433	0.00202
	7	179	483	70.8	0.00299	0.00111
	8	179	451	86.9	0.00493	0.00196
	9	208	419	87.2	0.00429	0.00213
	10	239	486	91.0	0.00438	0.00215
	11	1236	2055	99.8	0.00218	0.00131
				mean	0.00448	0.00237
1951	12	45	122	45.9	0.00593	0.00219
	13	48	118	52.2	0.00647	0.00263
	14	124	170	74.2	0.00475	0.00346
	15	126	200	71.8	0.00436	0.00275
	16	169	229	74.1	0.00347	0.00256
	17	289	689	80.1	0.00261	0.00102
	18	317	600	83.7	0.00249	0.00131
	19	331	643	91.7	0.00327	0.00168
	20	436	859	92.7	0.00261	0.00132
				mean	0.00400	0.00210
1952	21	92	193	57.1	0.00399	0.00190
	22	104	187	64.1	0.00428	0.00238
	23	121	234	60.5	0.00333	0.00172
	24	122	167	63.9	0.00363	0.00265
	25	133	286	67.6	0.00368	0.00171
	26	141	310	71.6	0.00388	0.00176
	27	145	203	67.7	0.00338	0.00242
	28	226	532	69.1	0.00226	0.00096
	29	241	616	84.4	0.00335	0.00131
	30	250	510	72.6	0.00225	0.00110
	31	256	481	79.3	0.00267	0.00142
	32	336	711	74.6	0.00177	0.00084
				mean	0.00321	0.00168
1953	33	95	216	57.6	0.00392	0.00173
	34	105	193	53.6	0.00318	0.00173
	35	107	98	69.6	0.00479	0.00523
	36	119	234	60.3	0.00337	0.00171
	37	127	117	83.7	0.00620	0.00673
	38	128	210	84.6	0.00635	0.00387
	39	134	127	89.3	0.00724	0.00764
	40	141	184	78.4	0.00472	0.00362
	41	171	220	82.7	0.00446	0.00346
	42	187	364	89.7	0.00528	0.00271
	43	242	646	73.2	0.00236	0.00089
	44	258	540	91.7	0.00419	0.00200
	45	278	518	80.6	0.00256	0.00137
	46	331	783	101.6	0.00664	0.00281
	47	387	713	71.7	0.00142	0.00077
	48	389	1008	74.4	0.00152	0.00059
	49	410	825	96.7	0.00361	0.00180
	50	451	949	99.2	0.00465	0.00221
				mean	0.00425	0.00283
				General mean	0.00400	0.00225

* $\frac{\text{NK yield} \times 100}{\text{NPK yield}}$

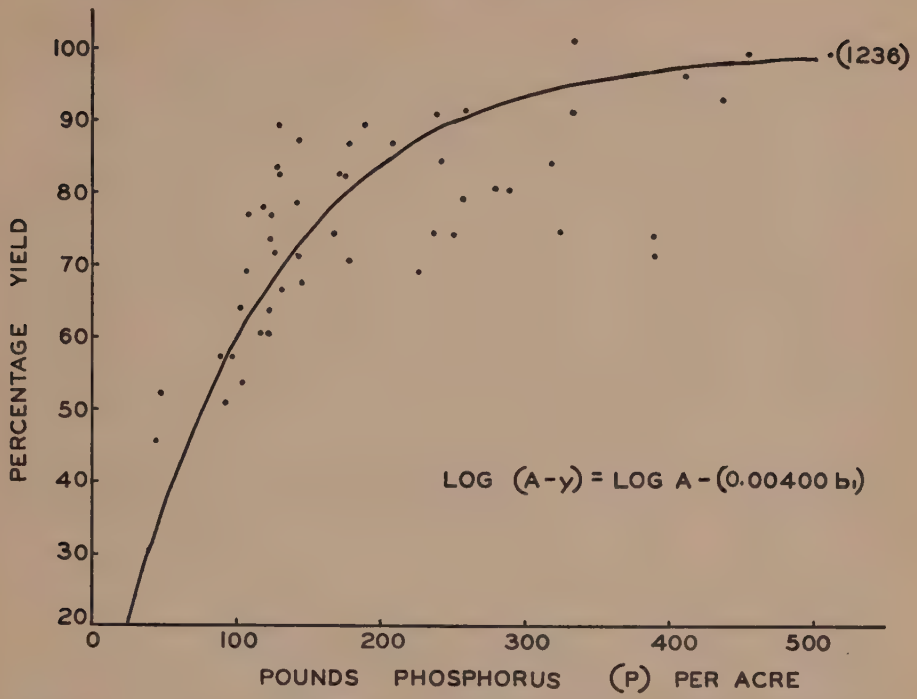

FIGURE 1. Relationship between percentage yield and soil test value (Bray's method).

solution was used as the extractant. In both cases the variation would conceivably have been reduced if uniform management methods and less variable soil conditions had prevailed in the field trials. The method, however, will be of practical value only if it shows reasonably close relationship over a relatively wide range of management efficiency and soil conditions. For this reason no rigid management control was attempted and soils of variable texture and reaction were included in the investigation. The general mean c_1 values given in Table 1 were used to calculate the data on which the curves in Figures 1 and 2 are based. These average curves represent the yield that may be expected at various soil phosphorus levels as shown by Bray's method or by extraction with K_2CO_3. Thus approximately 95 per cent of the maximum yield may be expected with a soil test value of 300 lb. per acre of phosphorus (P) by the Bray method or 600 lb. per acre of phosphorus (P) when K_2CO_3 is used as the extractant.

Arnold and Schmidt (1), on the basis of work in northern Illinois and southern Michigan, have reported that approximately maximum yields may be expected with soil test values of 160-180 lb. per acre of phosphorus (P) as determined by the Bray method. Their mean constant (c_1) was 0.0093 but the majority of the soils investigated had pH values from 5.1 to 6.5. The majority of the soils investigated in Prince Edward County were neutral or alkaline in reaction and pH values of 8.0 or even slightly higher were not uncommon. This difference in soil reaction may account, in part, for the difference between the results reported by Arnold and Schmidt and those obtained in this investigation.

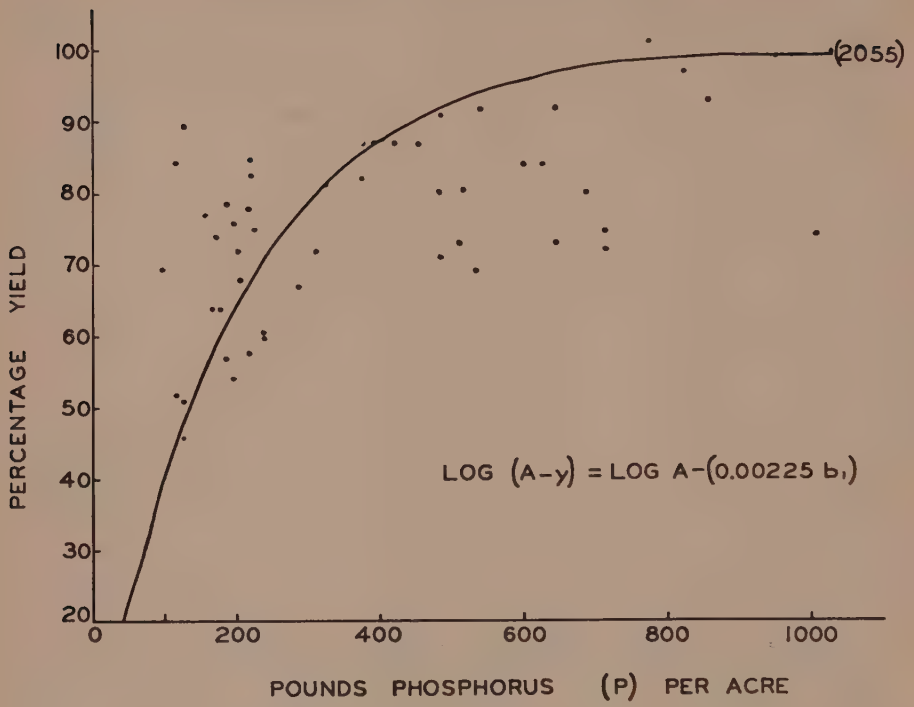

FIGURE 2. Relationship between percentage yield and soil test value (K_2CO_3 extraction)

Relationships Between Soil Test Values and Phosphatic Fertilizer Requirements

In the second phase of the study, field trials were designed to establish relationships between soil test values and the amounts of phosphatic fertilizer required to give maximum yields. Twelve trials, each with three replicates, were conducted in which the NK plot was bordered by an NPK plot and a plot receiving some fraction of the complete level of phosphatic fertilizer. In these comparisons the maximum levels of fertilizers applied were similar to those used in the first phase of the study. The soil test values as estimated by the two methods, the percentage yield of the plots receiving various increments of P_2O_5 and the calculated c values for the average of the three replicates in each of the twelve comparisons are presented in Table 2. The data have been arranged in four groups of approximately similar soil test values as obtained by the Bray method of analysis. Although considerable variability exists, the data indicate that the increment of fertilizer required decreased as the soil test value increased. In the soils testing 47-64 lb. of P by the Bray method, it is apparent that the increase of the fertilizer increment from 120-240 lb. per acre increased the per cent yield from 65.3 per cent to 93.9 per cent. It is of further interest to note that on a soil with a relatively low test value 240 lb. of P_2O_5 gave approximately maximum yield. Where 180 lb. of P_2O_5 were applied the soil test by the Bray method varied from 50-214 lb. per acre of P. On these soils the percentage yields ranged from 77.2 with the lowest test value to 98.5 with the highest. While the calculated c values show considerable

variation from the mean, it is considered that these mean values may be used for the tentative estimation of fertilizer requirements. Therefore equations 1 and 2 given below represent the relationship between the soil test value for phosphorus and the phosphatic fertilizer requirement for maximum yield in Prince Edward County when the phosphorus status of the soils has been estimated by the Bray and K_2CO_3 methods respectively:

Equation 1:

$$\text{Log } (A - y) = \text{Log } A - (0.004b_1 + 0.00366x).$$

Equation 2:

$$\text{Log } (A - y) = \text{Log } A - (0.00225\ b_1 + 0.00366x).$$

While other workers (1,4) have based the fertilizer requirement on 98 per cent of the maximum yield, it is felt that in view of the soil variation in Prince Edward County 95 per cent of the maximum would be a practical

TABLE 2.—SOIL TEST VALUES, PERCENTAGE YIELDS, AND C VALUES FOR 12 FIELD INCREMENT TRIALS

Trial No.	Soil test values lb./ac. P		Phosphorus increment lb./ac. P_2O_5	Percentage yield	c values	
	Bray	K_2CO_3			Bray ($c_1 = 0.00400$)	K_2CO_3 ($c_1 = 0.00225$)
1	47	136	120	65.3	0.00226	0.00128
2	64	83	160	78.1	0.00252	0.00295
3	50	136	180	77.2	0.00246	0.00187
4	49	121	240	93.9	0.00424	0.00393
5	89	231	180	83.6	0.00238	0.00147
6	95	98	180	85.7	0.00258	0.00347
7	88	197	200	83.2	0.00211	0.00166
8	153	203	155	94.9	0.00439	0.00539
9	159	116	160	99.4	0.00991	0.01226
10	183	236	180	92.4	0.00215	0.00327
11	241	506	105	95.3	0.00347	0.00175
12	214	435	180	98.5	0.00538	0.00469
				mean	0.00365	0.00367
				General mean	0.00366	

TABLE 3.—TENTATIVE SCHEDULE OF PHOSPHATIC FERTILIZER REQUIREMENTS FOR 95 PER CENT OF MAXIMUM YIELD OF TOMATOES IN PRINCE EDWARD COUNTY

Soil test Bray lb./ac. P	Percentage yield without P	Phosphorus requirement lb./ac. P_2O_5	Soil test K_2CO_3 lb./ac. P	Percentage yield without P	Phosphorus requirement lb./ac. P_2O_5
40	30.8	312	50	22.8	325
80	51.1	268	100	40.4	294
100	60.2	246	150	54.0	268
140	71.0	202	200	64.5	233
180	79.3	159	250	72.6	202
240	87.2	93	300	78.9	171
280	90.6	49	350	83.7	140
300	91.8	28	400	87.4	110
310	92.4	17	500	92.5	48
320	92.9	6	550	94.2	17

objective. Using 95 per cent of the maximum yield and equations 1 and 2 the phosphatic fertilizer requirements, expressed as pounds of P_2O_5 per acre, have been calculated for a range of soil test values. The results of these calculations are presented in Table 3. These data indicate that in this area very little phosphatic fertilizer is required if the soil tests 250 lb. per acre by the Bray method or 500 lb. per acre by the K_2CO_3 method. However, in view of the greater variability in the c_1 values obtained when a K_2CO_3 solution was used as extractant, the Bray method of soil analysis is considered more reliable for the area investigated.

As previously indicated, this paper has dealt primarily with the establishment of values (c_1) showing the relationship between soil tests for phosphorus and percentage yield. The constancy of the c_1 values obtained for the Bray method of soil analysis indicates that this method provides a reliable index of the phosphorus status of Prince Edward County soils and may be used to predict the relative yield increase to be expected from the use of phosphatic fertilizer.

The soil test percentage yield relationship does not in itself answer the question of how much phosphorus fertilizer is required to obtain maximum yield. While some data relative to this question have been presented these are of a tentative nature and may be revised as more field data become available.

REFERENCES

1. Arnold, C. Y., and W. A. Schmidt. Soil tests as a measure of phosphorus available to tomatoes on heavy soils. Soil Sci. 71 : 105-115. 1951.
2. Bray, R. H. Soil-plant relations: 1. The quantitative relations of exchangeable potassium to crop yields and to crop response to potash additions. Soil Sci. 58 : 305-324. 1944.
3. Bray, R. H. Soil-plant relations: II. Balanced fertilizer use through soil tests for potassium and phosphorus. Soil Sci. 60 : 463-473. 1944.
4. Bray, R. H. Correlation of soil tests with crop response to added fertilizers and with fertilizer requirement. Diagnostic techniques for soils and crops, pp. 58-86. American Potash Institute, Washington, D.C. 1948.
5. Bray, R. H., and S. R. Dickman. Adsorbed phosphorus in soils and their relation to crop responses. Proc. Soil Sci. Soc. Amer. 1941 (6) : 312-320. 1942.
6. Hockensmith, R. D., R. Gardener, and J. Goodwin. Comparison of methods for estimating available phosphorus in alkaline calcareous soils. Colo. Agr. Expt. Sta. Tech. Bull. 2. 1933.
7. Mitscherlich, E. A. Die Bestimmung des Dungerbedürfnisses des Bodens. 2nd ed. Verlagsbuchhandlung Paul Parey, Berlin. 1930.
8. Richards, N. R., and F. F. Morwick. Soil survey of Prince Edward County. Report No. 10 of the Ontario Soil Survey. 1948.

TOXICITIES OF VARIOUS INSECTICIDES TO CUCUMBER[1]

D. G. Harcourt and L. M. Cass[2]

Vegetable Insect Section, Entomology Laboratory, Ottawa

[Received for publication July 15, 1954]

ABSTRACT

In field experiments at Ottawa, 1950-1952, four applications of dusts of 1 per cent lindane, 1 per cent rotenone, 3 per cent methoxychlor, 3 per cent nicotine, calcium arsenate-talc (1-10), calcium arsenate-COCS (1-10), or COCS-talc (10-1) were neutral in their effects on the test plant, Straight Eight cucumber. Four applications of dusts of 3 per cent technical-grade DDT or 3 per cent aerosol-grade DDT caused severe stunting of the vines and markedly reduced yields. Eight applications of 1 per cent lindane dust gave increased yields in 1951, but did not influence yield in 1950 and 1952. Eight applications of 3 per cent methoxychlor dust were neutral in 1950 and 1952, but caused moderate stunting and yield reductions in 1951. Eight applications of either grade of DDT dust caused severe stunting and yield reductions each season. Severe foliage injury occurred in DDT-treated plots, slight to moderate injury in those treated with methoxychlor or COCS.

INTRODUCTION

The striped cucumber beetle, *Acalymma vitatta* (F.), is the most important insect pest of cucurbits in Eastern Canada. It is present in moderate numbers each season at Ottawa, and although it rarely reaches outbreak proportions it is frequently a serious pest in home gardens. In occasional years it causes significant damage to commercial plantings of cucumbers and melons, chiefly by disseminating the causal organism of bacterial wilt.

The objects of control measures are to prevent the adults from feeding on the young plants, which they frequently kill or stunt, and to prevent their introducing the wilt organism. At Ottawa, the main period of attack by the beetle extends from the time the plants appear above ground until they begin to form vines, approximately one month. But, to avoid spread of bacterial wilt, even in moderate infestations, it is necessary to keep a light coating of insecticide on the plants in June, July, and August. The present study was made to determine the reactions of cucumber to frequent applications of various insecticides.

That cucurbits are easily injured by insecticides has been reported by many workers (2, 3, 7). Others (1, 10, 15) have demonstrated that there are varietal responses to insecticides. Matthewman *et al.* (10), in tests on 12 commercial varieties of cucumber, found that Straight Eight was one of the most susceptible of those tested. Accordingly, Straight Eight was chosen as the test plant for the present study.

MATERIALS AND METHODS

Materials and Application

Table 1 shows the chemicals and the concentrations at which they were tested. The derris and calcium arsenate dusts are the materials currently recommended (11,12) for the control of the striped cucumber

[1] Contribution No. 3225, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Associate Entomologist and Technician.

beetle in Ontario. COCS, copper oxychloride sulphate, is one of the materials suggested for the control of anthracnose, and leaf spot diseases of fungus and bacterial origin (12). It is a common constituent of commercial cucumber and melon dusts. Nicotine dust, a material recommended in the past for cucumber beetle control, is of value against infestations of the melon aphid, *Aphis gossypii* Glov. These materials were tested in comparison with DDT, methoxychlor, and lindane.

The 3 per cent technical-grade DDT dust was from DDT of 88° C. minimum setting-point[1] and contained approximately 75 per cent *p-p'*-isomer. The 3 per cent aerosol-grade DDT was from DDT of 103° C. minimum setting-point[1] and contained approximately 93 per cent *p-p'*-isomer. The 1 per cent rotenone and lindane dusts were prepared in the laboratory, the latter from a product containing approximately 25 per cent gamma isomer of BHC, from lindane[2]. The 3 per cent methoxychlor dust was prepared in the laboratory from a product containing 88 per cent *p-p'*-isomer[3]. The 3 per cent nicotine dust, also prepared in the laboratory, was from a preparation containing 40 per cent nicotine sulphate. The copper oxychloride sulphate[4] contained 6 per cent copper. Excepting nicotine dust, the diluent of each insecticide was principally talc. Nicotine dust was diluted with hydrated lime.

The chemicals were applied with hand-operated, rotary-fan dusters at average rates of 30 lb. per acre of the diluted dust. The first application was made a few days after the plants appeared above the soil, at a time when 50 per cent of the first true leaves had expanded. The applications were made in the early morning when the plants were moist with dew. Because wind velocities were low at this time, insecticidal drift was minimal. The dusts were applied at average intervals of seven days, from June 30 to August 18 in 1950, from June 28 to August 17 in 1951, and from June 23 to August 12 in 1952. In 1950 there was a single schedule of eight applications; in 1951 and 1952 there were two schedules, of eight and four applications respectively.

Plot Arrangement, and Planting

Each plot consisted of two adjacent rows, 20 feet long and 6 feet apart. The experimental design in 1950 and 1951 was a randomized block with six and four replications respectively. In 1952, it was an 11 × 6 incomplete latin square. There were 60 plots in 1950, forming an experimental area of half an acre; 72 plots in 1951, two-thirds of an acre; 66 plots in 1952, three-fifths of an acre.

The cucumber seed was planted with a mechanical seeder on June 12 in 1950 and 1951, and on June 7 in 1952. Three weeks after planting, the seedlings were thinned to 6 inches between plants in the row; they were further thinned to 20 vines per row one week later, and to 10 vines two weeks later.

Criteria of Phytotoxicity

The following records were taken in each of the three seasons: (a) foliage injury; (b) estimates of plant size in square feet; (c) numbers of

[1] Green Cross Insecticides.
[2] California Spray Chemical Corp.
[3] Canadian Industries Ltd.
[4] Niagara Brand Spray Company.

TABLE 1.—EFFECTS OF 4 AND 8 APPLICATIONS OF INSECTICIDAL DUSTS ON SIZE OF CUCUMBER PLANTS*, OTTAWA, 1950-1952

Dust	Size of plants in square feet				
	4 applications		8 applications		
	1951	1952	1950	1951	1952
Calcium arsenate-talc, 1-10	311	878	655	329	907
Lindane, 1%	360	915	695	355	888
Methoxychlor, 3%	348	867	661	274	882
Calcium arsenate-COCS, 1-10	326	865	673	309	877
COCS-talc, 10-1	330	845	635	308	849
Rotenone, 1%	340	—	681	327	—
Nicotine, 3%	338	—	663	325	—
Aerosol-grade DDT, 3%	208	—	468	173	—
Technical-grade DDT, 3%	209	—	458	119	—
Check (no treatment)	338	921	671	338	921
Difference required for significance					
at 5% level	56	78	69	56	78
at 1% level	74	100	91	74	100

* 1950 and 1952, 120 plants per treatment; 1951, 80 plants per treatment.

fruit, and (d) weights of fruit, in ounces. In 1952, a record was taken as well on weights of vines at final harvest.

Eight records of foliage injury were taken at weekly intervals, beginning six days after the first application. At each inspection the injury to the foliage as a whole, of each plant, was recorded. After early August the individual plants could no longer be distinguished; each row was then divided into 10 sections corresponding to the number of plants, each section being treated as a separate entity. Records of plant size were taken one week after the eighth application. These consisted of estimates of the ground area covered by each row of plants. The numbers and weights of fruit were recorded every four or five days in August and September until frost had killed the plants. There were nine such records in 1950, between August 3 and September 19; seven in 1951, between August 8 and September 10; and nine in 1952, between July 31 and September 12. On each occasion, the vines were stripped of all fruit over 4 inches in length, until the final record, when all the fruit was picked. Although a killing frost had not occurred by September 12 in 1952, the final yield record was taken on this date to permit pulling and weighing of the vines. These data, obtained on September 13-16, are omitted because of their close agreement with the yield data.

RESULTS

The cucumber beetle infestation was moderate in 1950 and slight in 1951 and 1952. The beetles that were present were repelled from the field by the first application of insecticides. Loss of plants from bacterial wilt each year was negligible. Consequently, all plant responses may be considered directly due to effects of the chemicals.

Foliage Injury

In the 4-application schedule, only two materials caused consistent injury to the foliage. Technical-grade DDT and aerosol-grade DDT

caused severe burning of the foliage in the two seasons in which they were applied, the latter material almost as much as the former. COCS-talc caused very slight burning of the foliage in 1951; methoxychlor caused very slight chlorosis in 1952.

In the 8-application schedule, five materials were injurious to the foliage. Eight applications of technical-grade DDT or of aerosol-grade DDT caused more damage than four. Methoxychlor caused slight burning of the foliage in all three seasons. COCS-talc caused slight chlorosis each season; calcium arsenate-COCS was slightly injurious in 1951.

The symptoms of foliage injury caused by technical-grade DDT and aerosol-grade DDT are described in an earlier paper (10), and may be summarized as follows: Chlorotic areas appeared at the margins of the leaf, first as irregular bright-yellow to yellowish-green spots. Later these widened until the whole leaf except the vein network was yellowish. The veins retained their green colour, standing out darkly against the pale background. When severely injured, the leaves became misshapen, curled, and brittle to the touch.

The injury caused by methoxychlor consisted at first of a slight yellowing of the leaf margins and later of a faint mottling of the entire surface, the leaves at all times retaining their normal shape and texture. Leaves treated with COCS, alone or in combination with calcium arsenate, developed only occasional chlorotic areas in their centres, the chlorosis usually being restricted to the periphery of the leaf.

Stunting of Plants

Data on plant size are summarized in Table 1. In both 1950 and 1951, eight applications of technical-grade DDT or of aerosol-grade DDT caused severe reductions in the size of the plants, an average of 36 and 43 per cent, respectively. Eight applications of methoxychlor caused a moderate reduction in plant size, 19 per cent, only in 1951. Eight applications of the remaining materials were neutral in their effects.

Only DDT caused severe stunting of the plants when applied four times. In 1951, either grade of this material reduced the average plant size by 38 per cent.

Yield

The yield records provide the most significant criterion (Tables 2-4). Four applications of either grade of DDT seriously reduced the yield in 1951. Technical-grade DDT reduced the average number of fruits by 46 per cent, the average weight by 54 per cent; aerosol-grade DDT, 44 and 53 per cent, respectively. Four applications of the remaining materials had no significant effects on the yield.

In the 8-application schedule, four materials had significant effects on the yields. Each grade of DDT severely reduced the yield in each season that it was applied. Methoxychlor caused a moderate reduction in yield in 1951; the average number of fruits was reduced by 28 per cent, the average weight by 20 per cent. Only lindane increased the yield. Although it was neutral in its effects in 1950 and 1952, eight applications of lindane caused an increase in both numbers and weights of fruit in 1951, 28 and 22 per cent, respectively. On the whole, eight applications of the phytotoxic materials caused proportionately as much injury as did four,

TABLE 2.—EFFECTS OF 4 AND 8 APPLICATIONS OF INSECTICIDAL DUSTS ON YIELD OF STRAIGHT EIGHT CUCUMBER*, OTTAWA, 1950-1951

Dust	Yield, in number of fruits			Number as a percentage of that of the checks		
	Four applications	Eight applications		Four applications	Eight applications	
	1951	1950	1951	1951	1950	1951
Lindane	1,659	2,847	1,825	116·0	102·7	127·6
Rotenone	1,515	2,885	1,383	105·9	104·1	96·7
Calcium arsenate-COCS	1,583	2,754	1,356	110·7	99·4	94·8
Nicotine	1,398	2,915	1,315	97·8	105·2	92·0
COCS-talc	1,366	2,381	1,305	95·5	85·9	91·3
Calcium arsenate-talc	1,183	3,280	1,248	82·7	118·3	87·3
Methoxychlor	1,465	2,400	1,035	102·4	86·6	81·5
Aerosol-grade DDT	793	1,212	412	55·5	43·7	28·8
Technical-grade DDT	776	1,056	224	54·3	38·1	15·7
Check (no treatment)	1,430	2,772	1,430	—	—	—
Difference required for significance						
at 5% level	384	610	384			
at 1% level	510	918	510			

* 1950, 120 plants per treatment; 1951, 80 plants per treatment.

TABLE 3.—EFFECTS OF 4 AND 8 APPLICATIONS OF INSECTICIDAL DUSTS ON YIELD OF STRAIGHT EIGHT CUCUMBER*, OTTAWA, 1950-1951

Dust	Yield, in ounces			Weight as a percentage of that of the checks		
	Four applications	Eight applications		Four applications	Eight applications	
	1951	1950	1951	1951	1950	1951
Lindane	5,601	13,104	5,841	116·6	110·3	121·6
Rotenone	5,442	13,334	5,715	113·3	112·2	98·2
Nicotine	4,582	12,822	4,454	95·4	107·9	95·0
COCS-talc	4,727	11,123	4,329	98·4	93·6	90·1
Calcium arsenate-talc	4,293	13,603	4,144	89·4	114·5	86·3
Calcium arsenate-COCS	4,794	12,180	4,117	99·8	102·5	85·7
Methoxychlor	5,063	10,511	3,828	105·4	88·8	79·7
Aerosol-grade DDT	2,247	4,580	966	46·8	38·6	20·1
Technical-grade DDT	2,208	3,683	515	46·0	31·0	10·7
Check (no treatment)	4,803	11,880	4,803	—	—	—
Difference required for significance						
at 5% level	964	2,244	964			
at 1% level	1,328	2,958	1,328			

* 1950, 120 plants per treatment; 1951, 80 plants per treatment.

suggesting that the variety Straight Eight is insecticide-tender throughout its growth period. Invariably the number and weight of fruits produced by the plants corresponded closely (Tables 2 and 3).

TABLE 4.—EFFECTS OF 4 AND 8 APPLICATIONS OF INSECTICIDAL DUSTS ON YIELD OF STRAIGHT EIGHT CUCUMBER*, OTTAWA, 1952

Dust	Four applications				Eight applications			
	Yield		Yield as a percentage of that of the checks		Yield		Yield as a percentage of that of the checks	
	Number of fruit	Weight, in ounces	Number	Weight	Number of fruit	Weight, in ounces	Number	Weight
Calcium arsenate-talc	4,524	23,020	98·0	99·9	5,055	23,602	109·5	102·5
Lindane	4,974	22,825	107·8	99·1	4,808	22,719	104·2	98·6
Calcium arsenate-COCS	4,677	23,443	101·3	101·8	4,949	22,579	107·2	98·0
Methoxychlor	4,461	22,556	96·6	97·9	4,828	22,194	104·6	96·3
COCS-talc	4,580	21,858	99·2	94·9	4,015	19,317	87·0	83·9
Check (no treatment)	4,616	23,035	—	—	4,616	23,035	—	—
Difference required for significance								
at 5% level	987	3,877			987	3,877		
at 1% level	1,315	4,650			1,315	4,650		

* 120 plants per treatment.

Flavour-Testing

No off-flavours or off-odours that could be attributed to applications of lindane or methoxychlor were detected in either freshly sliced or pickled cucumber.

DISCUSSION

In the United States 10 per cent calcium arsenate dust (calcium arsenate-diluent, 1-9) has long been recommended for the control of the striped cucumber beetle. However, in Ontario the concentration recommended until recent years was as low as 1-19 because of the possibility of foliage injury. Not until 1951 was the concentration increased to 1-12. The present work shows that calcium arsenate, 1-10, may be safely applied to cucumber. Moreover, this concentration may be expected to give significantly better control; the results of Gould (5, 6) and Huckett (8) indicate that the toxicity of calcium arsenate to the striped cucumber beetle increases almost proportionately with concentration.

The deleterious effects to cucumber of dusts containing insoluble coppers have been noted by other workers (6, 14, 16). In a season of moderate to severe infestation, the phytotoxicity is likely to be unnoticed because the copper adds slightly to the control of the insect. However, in an average season, insoluble coppers may only add to the cost of control and are likely to be injurious. Further, their fungicidal properties are mediocre; according to Chupp and Leiby (4), none of the copper compounds are effective against anthracnose.

Not more than four applications of methoxychlor should be made to tender varieties of cucumber such as Straight Eight. Further applications may be expected to cause a significant amount of foliage injury; in about one season in three, moderate plant stunting and yield reduction may result.

Several entomologists have reported serious outbreaks of the melon aphid to have occurred following the use of DDT and methoxychlor on cucurbits (7, 9, 13). This did not occur at Ottawa, although there were light infestations of aphids in the experimental fields during the latter part of each season.

ACKNOWLEDGEMENTS

The authors are indebted to R. H. Backs and A. W. Rathwell for their valuable assistance in record-taking. The co-operation of the Consumer Section, Department of Agriculture, Ottawa, in making the flavour tests is gratefully acknowledged.

REFERENCES

1. Alban, E. K., and V. E. Keirns. The effect of rotenone, commercial and aerosol-grade DDT dusts on the total yield, grade and maturity of seven cucurbit varieties. Proc. Amer. Soc. Hort. Sci. 51 : 448-452. 1948.
2. Brown, H. D., and E. K. Alban. Susceptibility of some of the cucurbits to DDT injury. Proc. Amer. Soc. Hort. Sci. 49 : 320-324. 1947.
3. Chapman, R. K., and T. C. Allen. Stimulation and suppression of some vegetable plants by DDT. J. Econ. Ent. 41 : 616-623. 1948.

4. Chupp, C., and R. W. Leiby. The control of diseases and insects affecting vegetable crops. Cornell Ext. Bull. 206. 1953.
5. Gould, G. E. Studies on cucumber beetle control in 1935. J. Econ. Ent. 29 : 731-735. 1936.
6. Gould, G. E. The biology and control of the striped cucumber beetle. Indiana Agr. Expt. Sta. Bull. 490. 1944.
7. Hervey, G. E., and W. T. Schroeder. The varietal response of cucumbers to DDT control. J. Econ. Ent. 39 : 403-404. 1946.
8. Huckett, H. C. A contribution to the study of control measures for cucumber beetles, *Diabrotica duodecimpunctata* Oliv. and *vittata* Fabr. J. Econ. Ent. 22 : 405-411. 1929.
9. Leiby, R. W. Vegetable insect recommendations for 1954. Dept. Ent., Cornell Univ., Ithaca, N.Y. (*Mimeographed*). 1953.
10. Matthewman, W. G., D. G. Harcourt, L. M. Cass, and W. G. Friend. The varietal reactions of cucumbers to DDT and methoxychlor dusts. Canadian Ent. 82 : 102-111. 1950.
11. Matthewman, W. G. The striped cucumber beetle. Canada Dept. Agr., Div. Ent. Processed Pub. 101. 1951.
12. Ontario Department of Agriculture and Canada Department of Agriculture. Protection calendar for vegetables. Ontario Dept. Agr., Fruit Branch, Toronto. 1953.
13. Reid, W. J., and F. P. Cuthbert. Tests of insecticides for control of the pickleworm and associated insects on cucumbers and squash. U.S. Dept. Agr. BEPQ Bull. E-856. 1953.
14. Wilson, J. D. Certain injurious effects of spraying vegetables with the fixed coppers. Ohio Agr. Expt. Sta. Bi-monthly Bull. 25 : 36-43. 1940.
15. Wilson, J. D., and J. P. Sleesman. Some of the newer pesticides damage plants. Ohio Agr. Expt. Sta. Bi-monthly Bull. 32 : 58-63. 1947.
16. Wilson, J. D., and J. P. Sleesman. Pesticides. A study of their effects on the growth and transpiration of cucumber, tomato and potato plants. Ohio Agr. Expt. Sta. Bull. 676. 1948.

FACTORS AFFECTING THE LABORATORY EVALUATION OF SOIL CONDITIONERS

F. J. Brockman and O. C. W. Allenby[1]

Canadian Industries (1954) Limited, McMasterville, Que.

[Received for publication July 24, 1954]

ABSTRACT

Routine procedures for the evaluation of synthetic soil conditioners are based on the determination of the degree of stability of conditioned aggregates when exposed to the slaking action of water. This investigation has shown that the stability values obtained in a typical procedure vary with the moisture content of the aggregates during preparation, with the manner of incorporating the conditioner, with the degree of drying and ageing of the aggregates, and, under certain conditions, with the source of clay soil.

A procedure simulating practical application conditions was devised. Soil aggregate stability values given by this procedure were correlative with those obtained in the routine test when the aggregates for the latter test were prepared from soil of a crumbly consistency.

INTRODUCTION

The routine laboratory evaluation of soil conditioners commonly involves the preparation of conditioned soil aggregates and the measurement of the stability of these aggregates to the slaking action of water (1,2). An investigation of such a method in the authors' laboratory has shown it to yield markedly different results with variations in the manner of preparation of the aggregates[2]. An account of the effect of these variables is presented in this paper and the results obtained are compared with those from a procedure in which natural application conditions were simulated.

MATERIALS AND GENERAL METHOD

Samples of Ste. Rosalie clay subsoil from three different sites in the vicinity of Beloeil, Que., were used in the tests. The soil was pulverized to pass a sieve with 0.32 mm. openings prior to use in the evaluation procedure. Results of mechanical analyses on the sieved soils were as follows:

Soil sample	Per cent sand	Per cent silt	Per cent clay
A	6.80	20.64	72.56
B	9.44	27.00	63.56
C	12.00	20.80	67.20

[1]Present address: O. C. W. Allenby, du Pont Co. of Canada, Montreal, Que.

[2] Subsequent to the completion of this work a paper, "Laboratory evaluation of polyelectrolytes as soil conditioners", has been published by R. M. Hedrick (3). His paper contains some of the findings reported in this article.

Three commercial soil conditioners were employed in this investigation. Two of these were based on hydrolyzed polyacrylonitrile and are designated in the report as HPAN-1 and HPAN-2. The third contained as its active ingredient a vinyl acetate-maleic acid copolymer and is designated as VAMA.

Aggregates or soil crumbs were prepared by thoroughly mixing a 75-gm. sample of soil with a definite amount of water and conditioner. The mixing was conveniently carried out in a beaker using a wide (2 cm.) bladed spatula. In those determinations in which sufficient water was used to yield a pasty rather than a crumbly mixture, the mass was pressed through a 3.4 mm. sieve to form discrete particles. When the conditioner employed was added in the form of a powder, it was mixed with dry soil and water, then stirred in; when used in solution, it was diluted with the required amount of water and the resulting solution then added to the soil. The aggregates were air-dried for one day and then aged for a definite period (usually three days) at 25° C. and 40-50 per cent relative humidity. Per cent retention of aggregates to wet-sieving on a 0.32 mm. sieve was determined by the method of Geoghegan and Brian (1). The weight of water-stable aggregates is expressed as a percentage of the oven-dried (110° C.) soil.

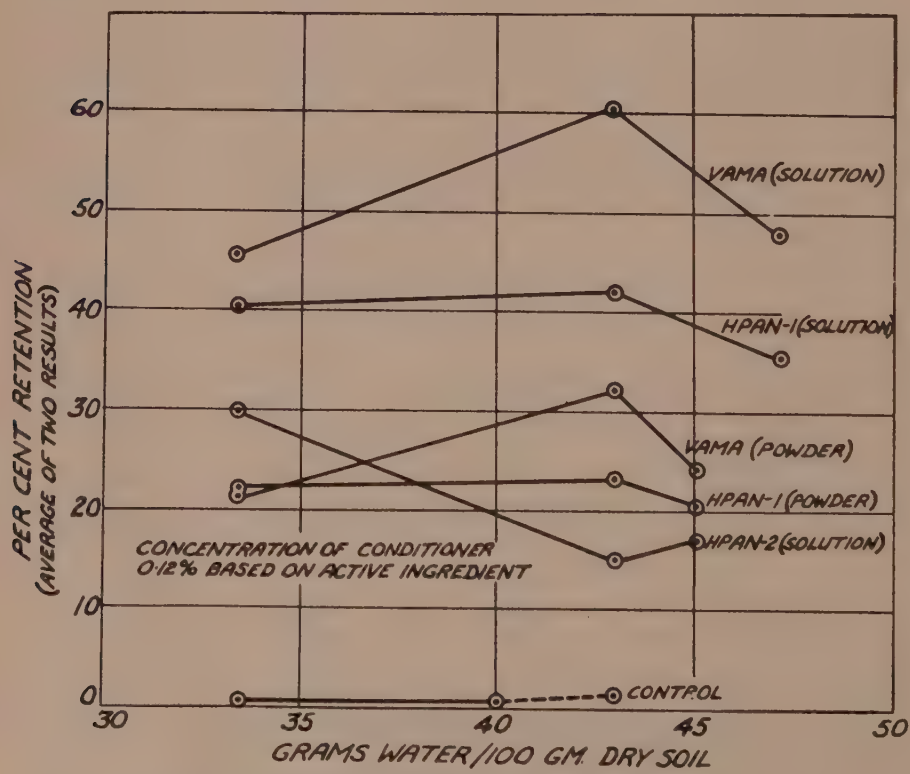

FIGURE 1. Variation of Per Cent Retention of Aggregates to Wet-Sieving with Initial Water Content of Aggregates (Soil C).

EXPERIMENTAL RESULTS

Effect of Variations in Preparation of Aggregates on Results in the Routine Procedure

Initial water content

The physical state of the aggregates when prepared varied markedly with the moisture content of the soil-water conditioner mixture. It was found with the Ste. Rosalie heavy clay soil employed that, at moisture contents up to 37 per cent* (unconditioned) or up to 47 per cent (conditioned), the soil sample broke up naturally into aggregates on stirring. Water tolerance of the soil was increased by the addition of conditioner, the increase being proportional to the efficiency of the conditioner. At higher moisture contents (up to 54-67 per cent) the soil became pasty and had to be pressed through a screen in order to form aggregates. Above this level the sample was of a slimy consistency and could not be converted into aggregates.

The per cent retention of aggregates in the test was found to be markedly dependent on the moisture content of the aggregates when prepared. This variation is undoubtedly allied with the degree to which the soil is compressed on stirring at different moisture contents. Figure 1 shows the results obtained from aggregates prepared from untreated soil (lot C) and soil treated with VAMA and HPAN formulations (0.12 per cent active ingredient) over a range of initial moisture contents. It will be noted that the efficiency of the conditioners as indicated by the difference in stability of the conditioned and non-conditioned soil varied markedly with initial moisture content. Moreover the efficiency of the different conditioners relative to one another also varied with initial moisture content. The same picture is apparent from an examination of Table 4.

Source of soil

The per cent retention of aggregates varied among the different samples of the Ste. Rosalie clay. This is illustrated in Table I which gives the results obtained with two lots of soil in the presence and absence of conditioner. It will be noted that the variation was marked when the moisture content was sufficiently high to yield pasty aggregates but was of less significance at crumbly consistencies.

* Grams water/100 gm. dry soil.

TABLE 1—VARIATION OF PER CENT RETENTION OF AGGREGATES IN ROUTINE SCREENING PROCEDURE WITH SOURCE OF STE. ROSALIE CLAY EMPLOYED

Conditioner	Per cent initial moisture	Per cent retention[1]	
		Soil A	Soil B
Control	33.3	1.1	1.6
Control	53.9	7.0	27.6
HPAN-1 (powder) 0.12% active ingredient	33.3	12.8	18.2
HPAN-1 (powder) 0.12% active ingredient	53.9	28.6	43.0

[1] Samples were air-dried for one day and aged for five days at 40-50% R.H./25° C. prior to wet-sieving.

Drying of the aggregates

The published procedures for the evaluation of soil conditioners by the wet-sieving technique specify air-drying the aggregates before wet-sieving. Table 2 summarizes the behaviour of conditioned and non-conditioned aggregates (prepared at an initial moisture content of 33.3 per cent) in the test before and after drying. A higher value for per cent retention of aggregates was obtained for all samples when the aggregates were wet-sieved without drying. Under these conditions, the stability of unconditioned soil samples also was comparatively high and the beneficial effect of the conditioner was much less apparent; actually, if the aggregates were aged at 100 per cent relative humidity prior to wet-sieving without drying, there was little difference between conditioned and non-conditioned soil.

TABLE 2—EFFECT OF DRYING OF AGGREGATES[1] ON PER CENT RETENTION OF AGGREGATES IN ROUTINE SCREENING PROCEDURE

Test No.	Conditioner	Treatment	Per cent retention
1	Control (soil B)	Sample aged wet for five days at 100% R.H./room temperature, air-dried one day and finally aged for one day at 40-50% R.H./25° C. prior to wet-sieving.	1.3
2	Control (soil B)	Sample wet-sieved at once without drying	13.6
3	Control (soil B)	Sample aged wet for five days at 100% R.H./room temperature, then wet-sieved without drying.	57.5
4	HPAN-1 (powder) 0.12% active ingredient.	Treatment as under No. 1	12.1
5	HPAN-1 (powder) 0.12% active ingredient.	Treatment as under No. 2	23.0
6	HPAN-1 (powder) 0.12% active ingredient.	Treatment as under No. 3	55.8

[1] Initial moisture content of aggregates was 33.3%.

The higher stability of the wet aggregates is probably associated with the reduced penetration of water during the wet-sieving operation. This reduced penetration would lessen the swelling and disintegrating effect on the soil crumbs. The increase in stability of wet aggregates on ageing at 100 per cent relative humidity could be due to the gradual hydration of the cations bound to the soil acid (acidoid), a phenomenon which is known to occur when dry soil is brought in contact with water. This hydration might be expected to have some cementing action on the soil particles and could possibly mask the effect of the conditioner.

It should be kept in mind in the extension of the observations to field conditions that drying of aggregates must occur ultimately and subsequent wetting of non-conditioned particles would result in extensive breakdown.

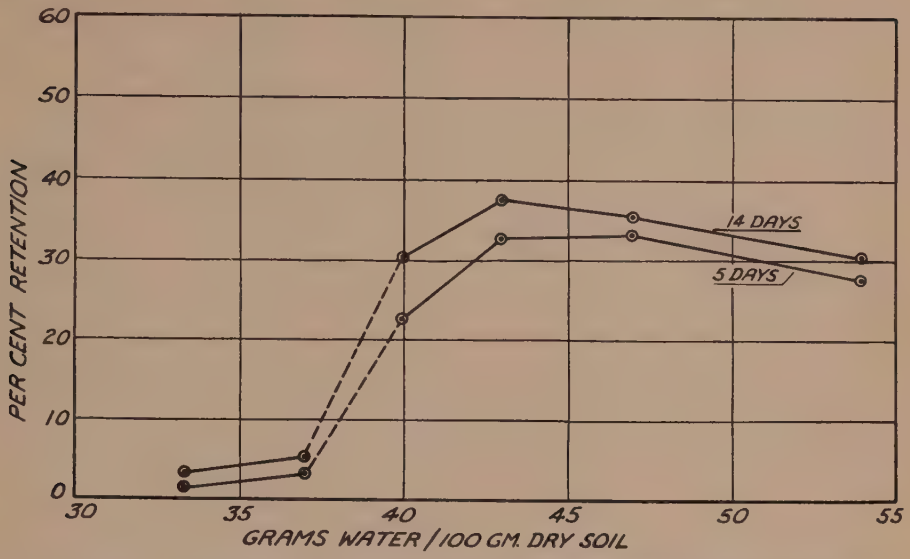

FIGURE 2. Variation of Per Cent Retention of Aggregates of Non-Conditioned Soil (Soil B) to Wet-Sieving with Ageing Time at 40-50 R.H./25° C.

Ageing of dried aggregates

An increase in per cent structure retention of aggregates was observed on ageing dried (containing approximately 3 per cent moisture) aggregates prior to wet-sieving. This phenomenon was observed with non-conditioned as well as conditioned soil (see Figures 2 and 3) and occurred whether the material was aged at 25° C. and 40-50 per cent relative humidity or in an oven at 50° C.

Method of incorporating conditioner into aggregates

The per cent retention of aggregates was also found to be markedly dependent on the manner in which the conditioner was added to the soil sample. Thus considerably higher values were obtained when the conditioner was added as a solution rather than mixed into the dry soil as a

TABLE 3—VARIATION OF PER CENT RETENTION OF AGGREGATES IN ROUTINE SCREENING PROCEDURE WITH METHOD OF INCORPORATING CONDITIONER INTO AGGREGATES[1]

Conditioner	Per cent active ingredient	Manner of addition of conditioner to soil	Per cent retention
Control (soil C)			0.82, 0.90
HPAN-1	0.12	Added as a powder	20.6, 23.4
HPAN-1	0.12	Added as a solution	36.6, 44.1
VAMA	0.12	Added as a powder	20.2, 22.2
VAMA	0.12	Added as a solution	42.3, 49.1
VAMA	0.075	Added as a powder	12.0, 13.8
VAMA	0.075	Added as a solution	39.0, 45.2

[1] Initial moisture content of aggregates was 33.3%. Aggregates were air-dried for one day and then aged three days at 40-50% R.H./25° C. prior to wet-sieving.

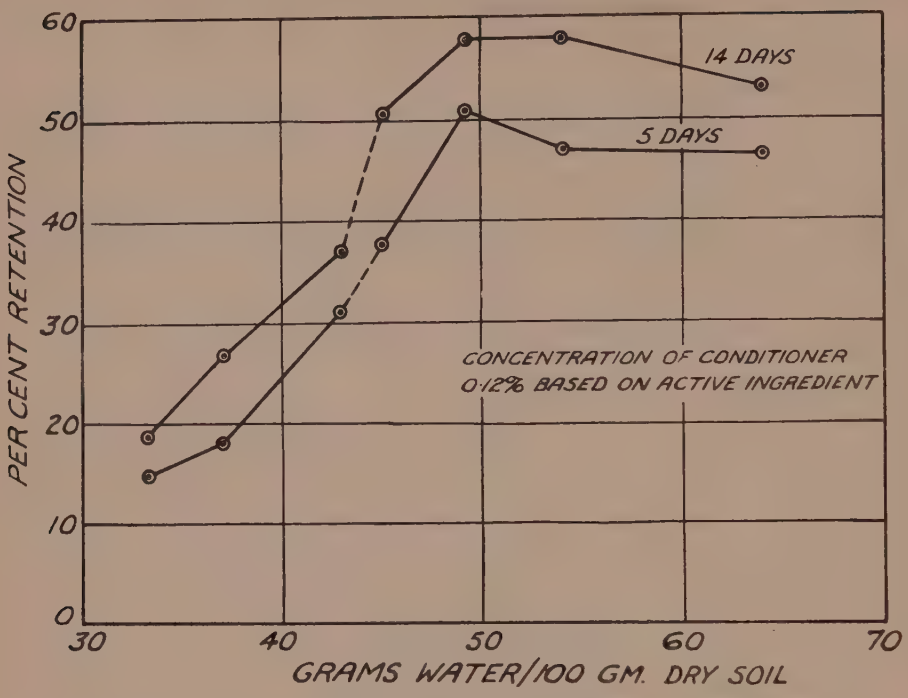

FIGURE 3. Variation of Per Cent Retention of Aggregates of VAMA Treated Soil (Soil B) to Wet-Sieving with Ageing Time at 40-50% R.H./25° C.

powder and water subsequently added (see Table 3). This held true whether aggregates were prepared at a crumbly or a pasty consistency. It indicates that solution of the solid conditioner in moist soil is incomplete under the conditions of the test and/or diffusion of the conditioner through the soil must be inefficient.

Comparison of Routine Procedure with Procedure Simulating Practical Application Conditions

Since the efficiency of different conditioners with respect to one another was found to be so dependent upon at least one variable, it was decided to check the results against a procedure more closely simulating that which would be used in the field. This procedure differed from the routine procedure in that the aggregates were formed prior to rather than simultaneously with the application of conditioner. Two modifications were tried:

Modification No. 1—The aggregates were formed by mixing soil with sufficient water to bring the moisture content to 30 per cent. They were then thoroughly mixed with conditioner. In tests in which a solution of the conditioner was used, the moisture content of the soil was reduced below 30 per cent by the amount of water added in the conditioner solution employed (i.e. to 24 per cent).

TABLE 4—COMPARISON OF PER CENT RETENTION OF AGGREGATES IN ROUTINE SCREENING PROCEDURE AND PROCEDURE SIMULATING ACTUAL APPLICATION CONDITIONS

Data pertaining to conditioner			Per cent retention in routine procedure[1]					Per cent retention in procedures simulating practical application conditions[2]	
Conditioner	Per cent active ingredient	Physical state	Aggregates of a crumbly consistency	Aggregates of a crumbly-pasty consistency	Aggregates of a pasty consistency				
			Initial moisture content 33%	Initial moisture content 43%	Initial moisture content			Modification No. 1	Modification No. 2
					40%	45%	47%		
Control (Soil C)			0.4, 0.4		0.5, 0.7			0.4, 0.45	2.5, 4.0
HPAN-1	0.12	powder	20.6, 23.4	23.2, 23.6		20.0, 21.4		4.7, 5.3	18 , 19
HPAN-1	0.12	solution	36.6, 44.1	41.2, 43.3			35.2, 35.9	17 , 21	42 , 43
HPAN-2	0.12	solution	26.8, 32.9	13.9, 15.2		17.1, 17.3		11 , 13	29.5, 30
VAMA	0.075	powder	12.0, 13.8			15.5, 16.3			
VAMA	0.075	solution	39.0, 45.2				32.8, 34.2	15 , 21	39 , 41
VAMA	0.12	powder	20.2, 22.2	31.4, 32.9		24.1, 24.3		6.5, 6.6	14 , 19
VAMA	0.12	solution	42.3, 49.1	56.0, 65.4			46.7, 49.4	20 , 20	44 , 46

[1] Samples air-dried one day and then aged three days at 40-50% R.H./25° C.
[2] Samples aged covered one day, air-dried one day and then aged for three days at 40-50% R.H./25° C.

Modification No. 2—Aggregates were formed as under Modification No. 1. They were dried to 3 per cent moisture content, mixed with conditioner and water added to bring the moisture content to 19 per cent.

The results obtained with a series of conditioners are given in Table 4. For purposes of comparison the corresponding values using the routine procedure at different initial moisture contents are included. It will be noted that the relative order of efficiency of the different conditioners is approximately the same in both modifications. Furthermore this order is in general agreement with that obtained in the routine test provided the aggregates for the latter test were prepared from soil in a crumbly rather than a pasty or near pasty state. As found in the routine test the method of adding the conditioner to the aggregates also markedly affected the results. Higher stability was obtained when the conditioner was applied to relatively dry aggregates which were subsequently wetted than when applied to damp or moist aggregates. Improved stability was also obtained when the conditioner was applied from solution rather than as a powder.

CONCLUSIONS

The results in this investigation indicate the importance of preparing the aggregates for the routine laboratory evaluation of soil conditioners under carefully standardized conditions. On the basis of the results obtained in the procedure simulating practical application conditions, it is concluded that the aggregates for the routine procedure should be prepared from a soil mixture having a crumbly rather than a pasty or near pasty consistency. It is also important in the preparation of the aggregates to add the conditioners being compared to the soil in an identical fashion and to evaluate any conditioner in the form in which it is to be used. Drying and ageing of the aggregates should also be carried out under standardized conditions. In the work of the authors, air-drying for one day followed by ageing for three days at 25° C. and 40-50 per cent relative humidity has been found to be a satisfactory schedule.

The extension of these findings to the application of conditioner in practice indicates that the method of application would be of considerable importance and would exert a marked effect on the efficiency of the conditioner. In the case of powder application best results should be obtained by allowing the soil to dry as thoroughly as possible before mixing in the conditioner and subsequently wetting the soil to assist penetration. Still better results could be expected from solution application, although in practice this would be considerably more difficult.

ACKNOWLEDGEMENT

The authors wish to thank J. A. Bélanger, Department of Agriculture, Experimental Station, L'Assomption, Que., for the mechanical analyses of the soil samples employed in this investigation.

REFERENCES

1. Geoghegan, M. J., and R. C. Brian. Aggregate formation in soil. 1. Influence of some bacterial polysaccharides on the binding of soil particles. Biochem. J. 43 : 5-13, 1948.

2. Hedrick, R. M., and D. T. Mowry. Effect of synthetic polyelectrolytes on aggretation, aeration, and water relationships of soil. Soil Science 73 : 427-442. 1952.

3. Hedrick, R. M. Laboratory evaluation of polyelectrolytes as soil conditioners. Agr. and Food Chem. 2 : 182-185. 1954.

THE USE OF ANION-EXCHANGE RESINS IN PHOSPHORUS FERTILITY STUDIES[1]

R. W. Sheard and A. G. Caldwell[2]

Ontario Agricultural College, Guelph, Ontario

[Received for publication July 12, 1954]

ABSTRACT

A phosphated anion-exchange resin, 1R-4B, was considered to be a suitable substitute for mono-calcium phosphate as a phosphorus standard for the determination of "A" values. Complete adsorption of phosphorus by the resin, Dowex 2, from aqueous solutions containing up to two p.p.m. phosphorus was obtained, but only 95 to 99 per cent recovery was possible by the procedure adopted. "A" values and soil phosphorus released to Dowex 2 in two hours for 24 Ontario soils were found to be significantly correlated ($r = 0.87$). A discussion of techniques involving anion-exchange resins as compared to methods requiring P^{32} is given and the anion-exchange technique is considered to have certain advantages in some soil phosphorus studies.

The experiments reported in this paper were designed: (*1*) to compare "A" values obtained from the use of mono-calcium phosphate to "A" values obtained from the use of resin-carried phosphate; (*2*) to determine "A" values for 24 Ontario soils using resin-carried phosphate in the greenhouse; (*3*) to study the adsorption of phosphorus from an aqueous solution of Dowex 2 and the subsequent release of the phosphorus, and (*4*) to determine the available soil phosphorus for the 24 soils by the use of the resin, Dowex 2.

Synthetic ion-exchange compounds have been used to considerable advantage in many research problems. Arnon and Grossenbacker (2) successfully grew lettuce and tomatoes in sand cultures, to which all the plant nutrients were added as cations or anions adsorbed on synthetic ion-exchange compounds. Fried[3] and Olsen *et al.* (9) have suggested the use of anion-exchange resins as a phosphate carrier for the determination of "A" values (7). Phosphorus in this form was considered to have an availability equal or slightly greater than phosphorus as mono-calcium phosphate, and less time was required for preparation.

Amer (1) investigated anion-exchange resins as a method of evaluating the phosphorus supplying power of soils. He found the resin, Dowex 2[4], would quantitatively adsorb soil phosphorus released to an aqueous suspension of a 1 : 1 ratio of soil to resin, over the pH and salt content of normal agricultural soils. The rate of phosphorus removal by the resin was found to be controlled by the concentration at the surface of the resin particle, and not by resin characteristics such as internal diffusion.

[1] Contribution of Department of Soils, Ontario Agricultural College, based on a thesis presented to the School of Graduate Studies, University of Toronto, as partial fulfilment of the requirements for the degree of Master of Science in Agriculture.

[2] Formerly Graduate Assistant, at present Lecturer, Department of Soils, Ontario Agricultural College; and former Lecturer, at present Assistant Professor, Department of Agronomy, Texas A. and M. College, College Station, Texas, respectively.

[3] Fried, M. (Plant Industries Division, U.S.D.A., Beltsville, Maryland). *Personal communication with the junior author, 1953.*

[4] Dow Chemical Company of Canada Limited, Sarnia, Ont.

MATERIALS AND METHODS

Samples of surface soil (Ac horizon), obtained from soil test calibration plots of the Department of Soils, Ontario Agricultural College, were used for this study.

Determination of "A" Values Using Resin-Carried Phosphate

A resin-carried phosphate material was prepared by adding 210 grams of air-dried resin, 1R-4B[1], to one litre of distilled water containing ten ml. of 85 per cent phosphoric acid. Approximately 375 microcuries of P^{32} per gram of P^{31} were then added. The solution was stirred at frequent intervals for six hours, at which time it was assumed that approximate equilibrium had been obtained. The supernatant liquid was decanted off and the resin washed with five 200 ml. portions of distilled water. A 2-gram sample of the air-dried resin was taken for each treatment which gave an application rate of 194 lb. of P_2O_5 per acre.

A P^{32} labelled, mono-calcium phosphate material was prepared by the method of Dion *et al.* (6). Samples of this material were taken to give a similar application rate to that of the resin-carried phosphorus. Nitrogen (N) and potassium (K_2O) were applied to all treatments at the rate of 150 lb. per acre and 200 lb. per acre, respectively.

Two pounds of soil were thoroughly mixed with the fertilizer material and five Proso millet (Panicum miliaceum L.), plants were grown in the soil for 42 days in the greenhouse. Four replications of each soil were used for the resin-phosphate material. A comparison of "A" values obtained from the two phosphorus materials was carried out on four soils using three replicates.

After wet-ashing the harvested plant material, total phosphorus was determined by the method of Barton (4) and fertilizer phosphorus was determined using a solution type of Geiger-Muller tube and procedures outlined by Spinks *et al.* (10). "A" values were calculated by the formulae proposed by Howling[2] in which

$$\frac{\text{Per cent } P_2O_5 \text{ derived from the soil}}{\text{Per cent } P_2O_5 \text{ derived from the fert.}} \times \text{lb. } P_2O_5 \text{ applied} = \text{"A" value}.$$

Available Phosphorus Determinations Using Dowex 2

Available soil phosphorus was measured using the anion-exchange resin, Dowex 2. The resin was air-dried and the 32- to 50-mesh fraction obtained. Representative samples of the different soils were ground to pass a 100-mesh sieve. A one-gram sample of soil was placed in a 250 ml. conical flask and one gram of resin was added. One hundred ml. of distilled water were added to the conical flask and the conical flask was placed on a reciprocating type of shaker for two hours. Separation of the 50-mesh resin from the 100-mesh soil was accomplished by washing on a

[1] Rohm and Haas Company, Philadelphia, Pa.

[2] Howling, H. L. The "A" value as a measure of the availability of soil and fertilizer phosphorus in Saskatchewan soils. Master's thesis, University of Saskatchewan. 1952.

60-mesh sieve with approximately 500 ml. of distilled water. The resin was quantitatively washed from the screen to a 250 ml. beaker with 10 per cent NaCl. Sufficient 10 per cent NaCl solution was added to make a total volume of approximately 50 ml. and the beaker placed on a steam bath for one hour. The solution was then filtered and the resin washed with hot 10 per cent NaCl solution until 100 ml. of leachate were obtained. Phosphorus was determined on an aliquot of the leachate by the Dickman and Bray (5) procedure. In order to compensate for the interference of NaCl on colour development of the phospho-molybdate complex, standards and unknowns were prepared so that they all contained 5 per cent NaCl.

EXPERIMENTAL RESULTS

Determination of "A" Values Using Resin-Carried Phosphate

A summary of the results from a comparison between "A" values obtained from resin-carried phosphate and from mono-calcium phosphate on four soils is given in Table 1.

TABLE 1.—COMPARISON OF PHOSPHATE MATERIAL FOR THE DETERMINATION OF "A" VALUES

Material	"A" value* (lb. P_2O_5 /acre)			
	Bondhead	Caistor	Guelph (No. 17)	Pontypool
Resin—$H_2P^{32}O_4$	165.8	200.2	207.2	458.0
Ca $(H_2P^{32}O_4)_2$	145.5	201.0	183.2	386.4

* Average of three replicates

L.S.D. Soils ($P = 0.05$) 53.7 lb. P_2O_5 per acre.
($P = 0.01$) 73.5 lb. P_2O_5 per acre.
Material N.S.

There was no significant difference between the "A" values obtained by the use of the two phosphate materials. Although the pH of these soils varied from 5.8 to 7.5 and the clay content ranged from 6.6 per cent to 38.5 per cent, the "A" values obtained by the use of the two different materials were essentially the same. A significant difference ($P = 0.01$) was found between the Bondhead and Pontypool soils used in this comparison.

"A" values recorded in Table 2, were determined for the 24 soils used in this study. A significant difference ($P = 0.01$) was obtained between "A" values for several of soils studied. The values ranged from a low of 49.2 to a high of 460.7 lb. of P_2O_5 per acre. The high value for sample No. 24 was believed due to past management. The sample was from a potato field which had received heavy applications of fertilizer and manure.

Available Phosphorus Determinations Using Dowex 2

A study of the adsorption of the phosphorus by the resin from an aqueous solution and the subsequent recovery of the resin was carried out. One gram of resin was shaken for two hours with 100 ml. of phosphate solutions containing 10, 25, 50, 75, 100 and 200 micrograms of phosphorus. Further treatment of the resin to study the adsorption and recovery was exactly the same as outlined for the soil and resin combined.

TABLE 2.—SAMPLE NUMBER, SOIL TYPE, "A" VALUE AND AVAILABLE PHOSPHORUS AS MEASURED BY RESIN TECHNIQUE FOR 24 ONTARIO SOILS

Sample No.	Soil type	"A" value* (lb. P_2O_5/acre)	Phosphorus release to Dowex 2** (lb. P_2O_5/acre)
1	Harriston loam	49.2	26.9
2	Hillsburgh sandy loam	67.7	36.4
3	Guelph loam	73.7	33.0
4	Huron clay	74.7	32.2
5	Hillsburgh sandy loam	76.0	35.7
6	Listowel silt loam	82.1	45.7
7	Falardeau silt loam	85.8	32.9
8	Schomberg silt loam	102.5	38.8
9	Harriston silt loam	109.3	51.6
10	Hillsburgh sandy loam	122.8	60.8
11	Honeywood silt loam	123.6	65.5
12	Fox sandy loam	128.4	53.4
13	Fox sandy loam	132.7	58.7
14	Bondhead silt loam	149.3	76.4
15	Honeywood silt loam	160.2	60.0
16	Honeywood silt loam	163.1	86.0
17	Guelph loam	180.4	72.9
18	Brookston clay loam	183.1	57.3
19	Fox loam	189.1	63.3
20	Caistor silty clay loam	201.4	88.9
21	Earlton silty clay loam	213.1	81.8
22	Fox sandy loam	214.5	89.9
23	New Liskeard clay	220.4	116.5
24	Pontypool sandy loam	460.7	120.3

* Average of 4 replicates.
** Average of duplicate determinations.
L.S.D. for "A" values (P = 0.05) 14.4 lb. P_2O_5 per acre.
(P = 0.01) 18.9 lb. P_2O_5 per acre.

TABLE 3.—THE ADSORPTION OF PHOSPHORUS BY ONE GRAM OF DOWEX 2 FROM AN AQUEOUS SOLUTION IN TWO HOURS AND THE RECOVERY OF THE ADSORBED PHOSPHORUS FROM THE RESIN WITH TEN PER CENT NaCl SOLUTION

Micrograms of P in orig. 100 ml.	Micrograms of P not recovered	Per cent adsorption	Per cent recovery by 10 per cent NaCl
10	0.5	100	95.0
25	1.5	100	94.2
50	1.5	100	97.0
75	2.1	100	97.2
100	1.1	100	98.9
200	1.2	100	99.4

The results of the adsorption study, reported in Table 3, are in agreement with results reported by Amer (1); 100 per cent removal of phosphorus from an aqueous solution by Dowex 2 was obtained over a range of 10 to 200 micrograms of phosphorus per 100 ml. However, the per cent recovery of phosphorus from the resin as reported in Table 3 was not entirely in agreement with results reported by Amer (1). He reported 98 per cent

recovery of phosphorus by Dowex 2 by a similar extraction procedure, but he failed to report the amount of phosphorus in the solution used for the adsorption study. Table 3 shows that, as the amount of phosphorus in the solution increased, the per cent recovery increases from 94.2 to 99.4 per cent, although the actual amount not recovered remains fairly constant at approximately 1.5 micrograms.

Amer (1) applied a factor to his results to correct for this incomplete recovery. As the amount of phosphorus not recovered was fairly constant at 0.5 to 2.1 micrograms, no corrections were made for incomplete recovery by the procedure used in this study. Available phosphorus as measured by the resin technique for the 24 soils is included in Table 2. It may be considered, however, that the soil phosphorus released to Dowex 2 in two hours may be 3 to 5 per cent below the true values. It will be noted that this procedure does not give as high a value for sample No. 24.

DISCUSSION AND CONCLUSIONS

On the basis of the results reported it is suggested that, where "A" value determinations are to be made in the greenhouse, isotopically labelled phosphorus, adsorbed on the anion-exchange resin, 1R-4B, may be used as a substitute for labelled mono-calcium phosphate. The material may be prepared in a few hours compared to several days required for the low temperature evaporation of large volumes of solution used in producing labelled mono-calcium phosphate.

It was found that the anion-exchange resin, Dowex 2, can be used to measure the phosphorus supplying power of Ontario soils. It was considered that the phosphorus was removed by the resin as rapidly as it was released by the soil to the soil solution. However, quantitative removal of the phosphorus from the resin was not possible by the technique adopted in this study. Therefore, it is suggested that further refinements of the regeneration procedure would add another valuable method to phosphorus fertility studies.

Certain points may be considered in comparing the resin technique to methods requiring P^{32}. Through the use of correlation analysis, it is possible to study the interrelationship between the different criteria for the phosphorus supplying power of soils. Correlation analysis of the data in Table 2 gave a significant correlation ($P = 0.01$) of $r = 0.87$.

The resin technique for measuring the phosphorus supplying power of the soil is based on the hypothesis that phosphate ions move from the soil particles to the soil solution and can be adsorbed by the resin particles. The resin continually removes any phosphate ions which may come into solution, thus preventing equilibrium of the phosphate ions between the soil particle and the soil solution. Amer (1) concluded that the available soil phosphorus released to the resin depends primarily on a combination of two fundamental properties of soil phosphorus: (*a*) the extent of dissociation of the phosphate ion from the soil, and (*b*) the accessibility of the phosphate ion to the soil solution.

In a review of the methods of phosphorus uptake by plants, Arnon (3) states:

> "A fresh appraisal of the evidence offers no compelling arguments against the view that water soluble phosphate is the source of phosphorus for plants grown under natural conditions in soil".

Accepting this statement in conjunction with the correlation between "A" values and available phosphorus measured by the resin technique, would suggest that the "A" value and the resin are measuring the same form of phosphorus in the soil, that is, that fraction which is available to the soil solution.

Amer (1) found that in any time-interval the amount of phosphorus adsorbed from the soil by Dowex 2 was numerically similar to the amount of soil phosphorus equilibrated with P^{32} by the procedure of McAuliffe *et al.* (8). This permits the measurement of the rate of release of phosphorus by the soil without the equipment of a radio-chemical laboratory.

The common method for extracting soil phosphorus is based on extraction with organic or inorganic acids or salts. These extraction methods will interfere with the natural release of phosphorus to the soil solution. The resin technique for determining the phosphorus supplying power of the soil has the advantage of not adding an acid or salt to the soil. It is possible, therefore, that the resin technique will give a true estimate of the phosphorus supplying power of the soil.

ACKNOWLEDGEMENTS

Appreciation is expressed to Canadian Industries, Limited, and the American Cyanamid Company, whose financial assistance helped make this investigation possible. The authors also wish to express their gratitude to the Dow Chemical Company of Canada, Limited, for the supplies of Dowex 2.

REFERENCES

1. Amer, F. W. Characterization of soil phosphorus by exchange resin adsorption and P^{32} equilibration. Doctor's dissertation, Iowa State College. 1953.
2. Arnon, D. I., and K. A. Grossenbacker. Nutrient culture of crop with the use of synthetic ion-exchange materials. Soil Sci. 63 : 159-180. 1947.
3. Arnon, D. I. The physiology and biochemistry of phosphorus in green plants. Soil and fertilizer phosphorus in crop nutrition. Academic Press Inc., New York, N.Y. 1953.
4. Barton, C. J. Photometric analysis of phosphate rock. Anal. Chemistry 20 : 1068-1073. 1948.
5. Dickman, S. R., and R. H. Bray. Colorimetric determination of phosphate. Ind. & Eng. Chem., *Anal. Ed.*, 12 : 665-668. 1940.
6. Dion, H. G., J. E. Dehm, and J. W. T. Spinks. Study of fertilizer uptake using radioactive phosphorus: IV. The availability of phosphate carriers in calcareous soils. Sci. Agr. 29 : 512-526. 1949.
7. Fried, M., and L. A. Dean. A concept concerning the measurement of available soil nutrients. Soil Sci. 73 : 263-271. 1952.
8. McAuliffe, C. D., N. S. Hall, L. A. Dean, and S. B. Hendricks. Exchange reactions between phosphate and soils: Hydroxylic surfaces of soil minerals. Soil Sci. Soc. Am. Proc. 12 : 119-123. 1947.
9. Olsen, S. R., C. W. Cole, F. Wetanabe, and L. A. Dean. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. Circ. 939. 1954.
10. Spinks, J. W. T., and S. A. Barber. Study of fertilizer uptake using radioactive phosphorus. Sci. Agr. 27 : 145-156. 1947.

EXPRESSION OF LEAF-ROLL PHLOEM NECROSIS IN POTATO TUBERS[1]

T. R. Davidson and G. B. Sanford[2]

Laboratory of Plant Pathology, Edmonton, Alta.

(Received for publication June 3, 1954)

ABSTRACT

The development of potato tuber leaf-roll phloem necrosis in relation to the period when the growing plant becomes infected was studied for four years in field experiments. The susceptible varieties, Carter's Early Favorite and Netted Gem, were graft-inoculated at 10-day intervals beginning with very young plants. The expression of tuber phloem necrosis was very low for early inoculations, but gradually increased during July, until the peak-period during the time of most rapid growth of the tubers, which in these experiments was about mid-August. This conclusion is based on the percentage of the inoculated plants that developed affected tubers, the percentage of affected tubers per plant and to some extent on the amount of necrosis in the tubers.

INTRODUCTION

Phloem necrosis of the tubers of *Solanum tuberosum* L., as caused by the potato leaf-roll virus, was first described in 1914 by Orton (5), who called this malady 'net necrosis' because of the characteristic netted pattern produced in the tuber. However, Orton did not associate phloem necrosis with the leaf-roll virus. This relationship was first established by Quanjer *et al.* (6) in 1916. Botjes (1) in 1920 showed that *Myzus persicae* Sulz., is an insect vector of the virus. In 1921 Schultz and Folsom (8), and also Gilbert (4) in 1928, showed that net necrosis was produced in tubers only when healthy vines became infected with the virus. Gilbert (4) mentioned that the phloem elements in the vines grown from the progeny of leaf-roll infected plants continued to develop necrosis year after year, whereas in the tubers these elements did not develop necrosis after the initial infection. No explanation has yet been given for this difference in behaviour between the vines and the tubers.

In the early stages of the present study at Edmonton it was observed that in September, when the tubers were dug, phloem necrosis had been much more severe and general one season than another, and that, in addition, it could develop later in storage. This observation suggested that the prevalence of tuber phloem necrosis might be associated indirectly with the size of population of the insect vector of the host, but Davidson (2) has shown that non-viruliferous *M. persicae* feeding on healthy vines are not responsible for the incidence of tuber phloem necrosis. In this paper, data will be presented to show the relationship between the development of tuber phloem necrosis and the stage of growth at which the plant becomes infected with the leaf-roll virus.

[1] Contribution No. 1396 from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa, Ontario.

[2] Associate Plant Pathologist and Plant Pathologist-in-Charge, Plant Pathology Laboratory, Edmonton, Alberta.

MATERIALS AND METHODS

Most of the materials and methods employed in this study have been given in greater detail in a previous publication (3). Thirty healthy potato plants of each of two varieties, namely, Netted Gem and Carter's Early Favorite, were graft-inoculated at 10-day intervals, beginning June 15, soon after the sprouts appeared above ground, and continuing until early in September. Graft-inoculation was employed in order to avoid any possible indirect influence of the insect vector. The experiment was carried out in field plots. In order to eliminate the error that might arise from multiple stalks, only one stalk was allowed to grow from a set. Terminal scions about $1\frac{1}{2}$ inches long were taken from infected indexed stock of the Canus variety. The scions were inserted in longitudinal cuts made in the stalks of actively growing, healthy plants, and firmly bound in place by a strip of rubber dental dam fastened with rubber cement. Weekly applications of an insecticide effectively protected the experimental plants from the insect vector.

During late September four tubers, which often were about 75 to 100 per cent of the total yield, were collected from each test plant and stored separately at a temperature of between 36° and 40° F. Early in February these tubers were examined for necrosis, and leaf-roll infection was confirmed in the greenhouse by the tuber-index method.

The data illustrated in the chart in Figure 1 refer only to the tuber necrosis as observed at the end of four months of storage and not to the necrosis at the time the potatoes were dug. Further, the dates given are approximately those when infection of the entire plant occurred, which, according to unpublished data, and assuming ideal conditions for quick scion union, is about 10 days after inoculation.

RESULTS

In analysing the results, the writers wish to emphasize several main points. The virus reached the stolons on or before the date listed in the chart in Figure 1. Also most of the tubers from which the data were secured were formed between June 29 and July 29, and about 50 per cent of them had formed by July 15. The most rapid increase in the size of tubers occurred in August, from the early part to the middle of the month (Table 1). After this date the rate of increase diminished and probably ceased early in September. Apparently the tuber growth tended to start slightly earlier and stopped sooner in the Carter's Early Favorite, a mid-season variety, than it did in Netted Gem, which is a late variety (Table 1). In general, this pattern of tuber development in the two varieties was similar for the three years' test with Carter's Early Favorite and for the four years with Netted Gem. Any yearly fluctuations in this pattern might have been caused by differences in soil moisture content or by temperature or even light intensity. Another point to emphasize is that practically all 'eyes' in an infected tuber carry the virus (7). This has been repeatedly confirmed throughout the course of this study, both by tuber index tests and by tuber unit field tests involving about 350 tubers. Finally, the data given on phloem necrosis refer to its presence or absence and not to the extent of it in the tuber.

TABLE 1.—AVERAGE NUMBER AND SIZE OF TUBERS PER PLANT DURING SEASON

Variety	Year	Tubers	June			July			August			
			15	21	29	6	12	20	24	2	12	23
Netted Gem	1950	Number	0	—	*1.0*	*4.0*	—	3.0	—	—	3.0	—
		Size*	0	—	0.1	0.2	—	0.5	—	—	4.0	—
	1951	Number	—	0	*1.4*	—	*3.6*	—	*5.4*	10.0	5.8	6.4
		Size*	—	0	0.2	—	0.5	—	0.9	1.8	2.7	3.6
Carter's Early Favorite	1950	Number	0	—	0	*1.5*	—	*4.0*	—	—	4.0	—
		Size*	0	—	0	0.2	—	0.2	—	—	3.0	—
	1951	Number	—	0	0	—	*5.2*	—	*6.0*	5.4	6.0	7.0
		Size*	—	0	0	—	0.7	—	1.2	2.4	3.4	3.8
	1953	Number	0	0	*1.1*	*4.0*	*5.3*	*7.0*	*7.7*	(cloudburst		
		Size*	0	0	0.2	0.3	0.3	0.7	1.1	destroyed test)		

* Length in inches.

The inoculum employed in this experiment was kindly analysed for strains of leaf-roll virus by R. H. Larson, University of Wisconsin. From one of the six Carter's Early Favorite tubers sent to him, he identified Strain 1, and from four of them Strain 3 (9). Our data show that both strains cause tuber phloem necrosis and, therefore, their presence does not affect the data in this paper.

The correlation lines in Figure 1, representing the average data for both varieties, are of the same general pattern. However, results determined after storage show that wide yearly fluctuations in necrosis occurred in Netted Gem tubers during the four years of the test, whereas a remarkable similarity in extent of necrosis was observed in Carter's Early Favorite for each of the years of the test. Tubers of the latter variety, then, are more susceptible to the development of phloem necrosis.

For Carter's Early Favorite the highest average percentage of plants yielding necrotic tubers involved those grafted about August 15. For Netted Gem this peak was reached by plants grafted about August 15 in 1949, August 25 in 1950 and 1952, and about August 5 in 1951. However, the percentage of plants bearing necrotic tubers varied widely during the growing season. For Carter's Early Favorite the percentage increased sharply in 40 days from nearly zero on July 5 to nearly 100 per cent on August 15; then it decreased about 15 per cent during the next 10 days, 12 per cent the following 10 days, and then fell to zero. In Netted Gem the increase was more gradual from the beginning, and it reached a much lower average peak than Carter's Early Favorite.

In the infection curves of the two varieties there was the same rapid decline from their respective peaks. Up to June 29 the number of tubers formed per plant rarely exceeded one; and about 50 per cent of them had formed by July 15 (Table 1). The very low percentage of plants having necrotic tubers from the early inoculations, and the rapid increase in this percentage during the period of tuber formation, indicates that if the virus reaches the stolons before tubers are formed the tubers do not develop

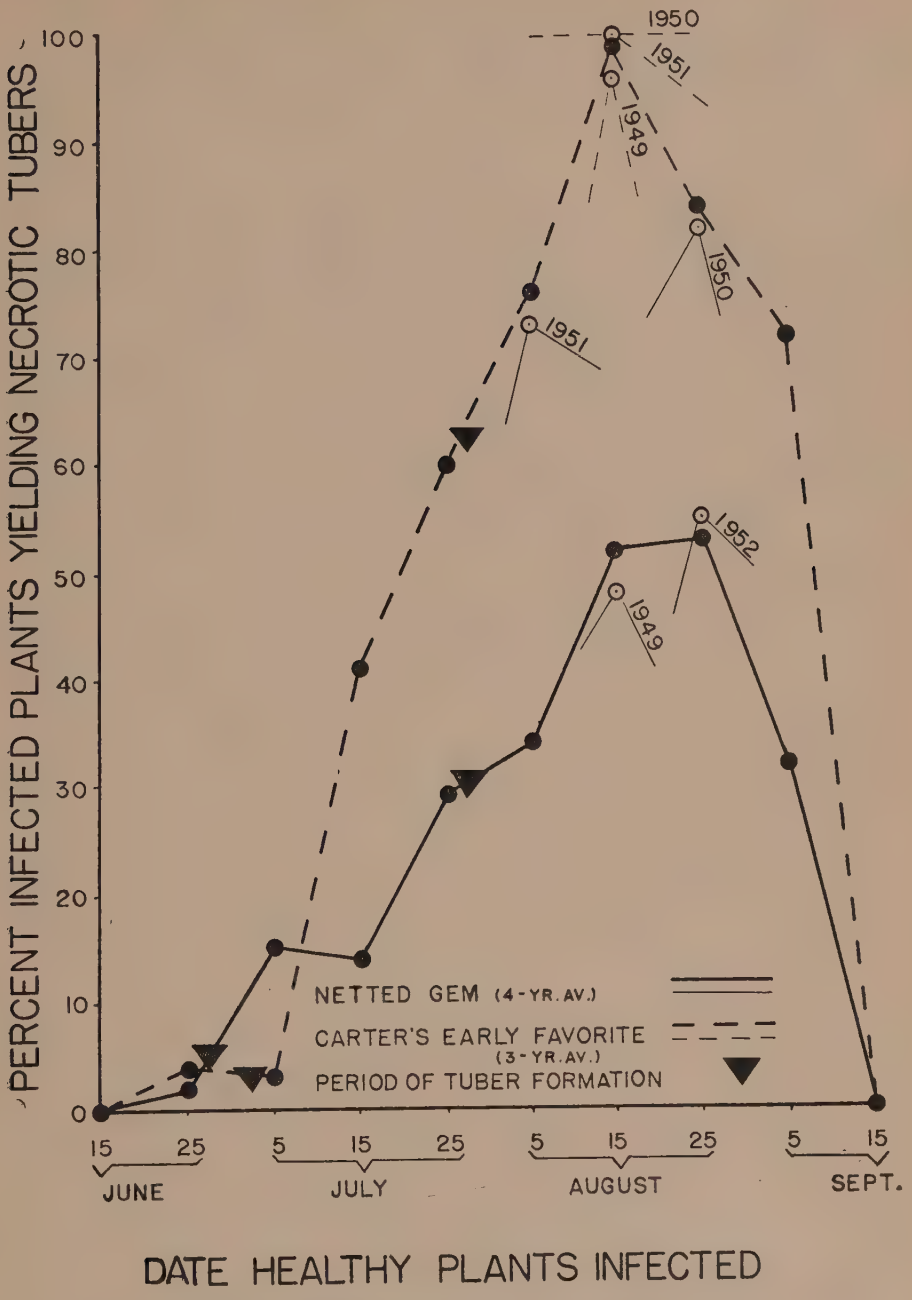

FIGURE 1. Relation of stage of growth in potato plants, when infected with leaf-roll virus, to development of tuber phloem necrosis.

phloem necrosis. Thus it would appear that at least a part of the low percentage of plants that, under field conditions, develop necrotic tubers might be the result of the prevalence of early infections with leaf roll.

Throughout the season, in both varieties, some of the tubers in a 'necrotic' hill did not develop phloem necrosis. This difference was very obvious in the early inoculations.

DISCUSSION

The data presented in Tables 1 and 2, and Figure 1, show that the incidence as well as the extent of tuber phloem necrosis in susceptible varieties may be delicately balanced and also closely associated with the particular stage of growth of the tuber when the leaf-roll virus enters it. Undoubtedly a number of varieties differ widely in inherent ability to develop phloem necrosis, but it is possible that nutrition, as affected by factors of the environment, might modify or intensify this character. For example, both varieties used in the study freely developed tuber phloem necrosis. Netted Gem does so less freely than Carter's Early Favorite, whereas the varieties Canus and Katahdin are both susceptible to the virus, but apparently do not have the ability to develop phloem necrosis in their tubers. For these reasons it seems possible that such differences exist in the contents of the phloem elements and perhaps they are enzymatic in nature.

The data given clearly show that during the three or four years of the test the highest percentage of infected plants producing necrotic tubers occurred when the virus entered the stolon after the tubers had formed, and during the period when they were enlarging most rapidly. This active period of growth (Table 2) was between August 1 and August 25. When inoculated about August 15 practically 100 per cent of the Carter's Early Favorite plants yielded necrotic tubers. For Netted Gem a lower average peak was reached in the plants grafted about 10 days later. When the plants were grafted after this period, such percentage dropped rather sharply to zero. The fact that the more gradual increase in percentage of plants having necrotic tubers was noted in those that were grafted before August might be explained partly by the fact that progres-

TABLE 2.—LEAF-ROLL PHLOEM NECROSIS IN POTATO TUBERS* AS AFFECTED BY DATE VIRUS BECAME SYSTEMIC

Variety	Year	Date plants infected									
		June		July			August			September	
		15	25	5	15	25	5	15	25	5	15
		%	%	%	%	%	%	%	%	%	%
Netted Gem	1949	—	—	14	31	47	35	48	32	37	—
	1950	0	0	12	13	25	26	68	82	33	—
	1951	—	4	19	4	—	73	67	44	12	0
	1952	—	—	—	7	14	0	25	55	45	0
Carter's Early Favorite	1949	—	—	5	37	31	50	96	62	55	—
	1950	0	0	4	46	90	100	100	100	83	—
	1951	—	7	0	40	—	79	100	92	77	0

*Per cent infected plants yielding necrotic tubers.

sively fewer tubers formed after the virus reached the stolons. However, it would seem that the line representing the incidence of necrosis from the earlier plant inoculations (Table 1) would be related to the accelerating growth of the tubers as affected by their nutrition.

REFERENCES

1. Botjes, J. O. De bladrolziekte van de Aardappelplant. H. Veeman, Wageningen. 1920.
2. Davidson, T. R. Phloem necrosis of potato tubers in relation to leaf roll free *Myzus persicae* Sulc. Can. J. Res., *C*, 28 : 283-287. 1950.
3. Davidson, T. R., and G. B. Sanford. Effect of age of potato foliage on expression of leaf-roll symptoms. Can. J. Bot. 32 : 311-317. 1954.
4. Gilbert, A. H. Net-necrosis of Irish potato tubers. Vermont Agr. Expt. Sta. Bull. 289. 1928.
5. Orton, W. A. Potato wilt, leafroll and related diseases. U.S. Dept. Agr. Bull. 64. 1914.
6. Quanjer, H. M., Lek, H. A. A. van der, and Botjes, J. O. Aard, verspriedingswijze en bestrijding van phloemnecrose en verwante ziekten. Meded. van de Landbouwhoogeschool Wageningen, 10 : 1-138. 1916. *In* Expt. Sta. Record 36 : 847. 1917.
7. Sanford, G. B., and J. G. Grimble. Observations on phloem necrosis of potato tubers. Can. J. Res., *C*, 22 : 162-170. 1944.
8. Schultz, E. S., and D. Folsom. Leaf roll, net-necrosis and spindling sprout of the Irish potato. J. Agr. Res. 21 : 47-80. 1921.
9. Webb, R. E., R. H. Larson, and J. C. Walker. Relationships of potato leaf roll virus strains. Univ. of Wisconsin Res. Bull. 178. 1952.

RATE OF DEVELOPMENT OF POTATO LEAF-ROLL VINE SYMPTOMS[1]

T. R. Davidson[2]

Plant Pathology Laboratory, Edmonton, Alta.

[Received for publication June 3, 1954]

ABSTRACT

Under greenhouse conditions and air temperature of about 68° F., the virus of potato leaf-roll, as indicated by vine symptoms, was effectively transferred by *Myzus persicae* to 85 per cent of young plants in from 15 to 17 days and to 100 per cent of them in 18 days. Stem graft inoculation was also effective, but, in general, it required about 5 days longer for symptoms to develop. This delay might be caused by the relatively slow union of the severed phloem elements of test plants.

INTRODUCTION

Schultz and Folsom (4), in 1921, reported that in an experiment in the greenhouse leaf-roll symptoms appeared on the foliage in from 24 to 29 days following virus inoculation of healthy potato plants by *Myzus persicae* Sulz. In 1931, Smith (5) reported that 14 days after inoculation by this insect, and under greenhouse conditions, leaf-roll symptoms appeared on the foliage. Bradley and Ganong (1), using this vector, found that the virus reached the tubers in from 8 to 20 days after vine inoculation, but they did not mention the period necessary for the symptoms to develop on the foliage. Murphy and M'Kay (3), 1926, found that under greenhouse conditions the virus, from top stem grafts, had reached all parts of the vines and tubers after an interval of more than 8 to 10 days and less than 14 to 15 days. The period required for vine symptoms was not mentioned. Davidson and Sanford (2), 1954, reported that the symptoms of leaf-roll were expressed on the foliage of field grown plants about 29 days after graft inoculation. In these experiments, it appeared that a minimum of about 10 days contact of vine and scion was necessary before actual infection could occur. The purpose of the tests reported in this paper was to compare, on young plants in the greenhouse, the time required for leaf-roll symptoms to develop on the foliage following inoculation by viruliferous aphids and by stem grafts.

METHODS

Healthy young potato plants of the Carter's Early Favorite variety were grown in pots in the greenhouse during early April, when the air temperature was about 68° F. The tuber identity and health of each plant was known. Controls consisted of one plant from each tuber tested.

For graft inoculation, wedge-shaped scions from infected potato plants were inserted in the stems of test plants (2) and then removed at intervals as mentioned in Table 1. For inoculation with aphids, 10 insects which had fed on leaf-roll plants, were placed on one of the lowermost leaves of each test potato plant for 3 days.

[1] Contribution No. 1398 from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa, Ontario.

[2] Associate Plant Pathologist.

TABLE 1.—EFFECT OF METHOD OF INOCULATION ON INCIDENCE OF VINE SYMPTOMS OF LEAF-ROLL ON YOUNG POTATO PLANTS IN THE GREENHOUSE

Days for vine symptoms to appear	Young potato plants inoculated in greenhouse*			
	Inoculation means		Infected scion removed from stock	Plants showing symptoms
	Myzus persicae	Graft		
	%**	%**	days	%**
15	5	0	0	0
16	60	0	4	0
17	25	11	8	20
18	10	14	10	60
21	—	25	12	80
22	—	42	15	100
23	—	3	Scions not removed	100
25	—	5		
	100	100		

* April.
** Plants positive; each percentage based on 20 plants.

DISCUSSION AND RESULTS

The data in Table 1 show that under the conditions of the experiment all the test potato plants could become infected by either the insect or the graft inoculation method. Under field conditions, and particularly in older plants, the graft method (2) may not be so uniformly effective as it was in this greenhouse experiment. The expression of leaf-roll symptoms on 90 per cent of the plants by the end of 17 days after viruliferous *M. persicae* had fed on the leaves suggests that the insect placed the virus in the phloem elements without injuring them, and that from this relatively small start the virus multiplied and spread to other parts of the plant. The expression of vine symptoms following the graft method was not only delayed but it was more irregular than that which occurred following insect inoculation. A possible explanation is that union between the severed phloem element of scion and stalk would have to take place before the virus could be transmitted and symptoms occur. Also, the irregular location of these phloem elements would favour some unions sooner than others. Despite this lag in infection it is apparent from both these experiments and from the field experiment reported earlier (2) that the graft inoculation method can be reasonably effective on young plants. The reason why a longer average time is required for foliage symptoms to develop under the cooler field conditions was not determined. The data in the right-hand section of Table 1 reveal that actual infection following the graft method of inoculation usually does not take place until after 5 to 6 days, and that no appreciable amount of transmission of the virus

from scion to stalk occurs in less than 10 days. When the diseased scions were removed from the healthy test plants at the end of 8 days only 20 per cent of them had become infected, and after 10, 12, and 15 days, 60, 80, and 100 per cent, respectively, had become infected. Once union of the severed phloem elements becomes established, the large reserve of virus in the infected scion can spread and soon induce foliage symptoms throughout the plant.

REFERENCES

1. Bradley, R. H. E., and R. Y. Ganong. Note on the time potato leafroll virus takes to pass from aphids on the leaves into the developing tubers. Can. J. Botany 31 : 143-144. 1953.
2. Davidson, T. R., and G. B. Sanford. Effect of age of potato foliage on expression of leaf-roll symptoms. Can. J. Botany 32 : 311-317. 1954.
3. Murphy, P. A., and R. M'Kay. Methods for investigating the virus diseases of the potato, and some results obtained by their use. Sci. Proc. Roy. Dublin Soc., n. ser., 18 : 169-184. 1926.
4. Schultz, E. S., and D. Folsom. Leaf roll net necrosis and spindling spout of the Irish potato. J. Agr. Res. 21 : 47-80. 1921.
5. Smith, K. M. Studies on potato virus diseases IX. Some further experiments on the insect transmission of potato leafroll. Ann. Appl. Biol. 18 : 141-157. 1931.

THE EFFECTS OF TWO SOIL CONDITIONERS ON SOME PHYSICAL PROPERTIES OF A BROOKSTON CLAY SOIL[1]

E. F. Bolton[2], J. M. Fulton[3] and J. W. Aylesworth[4]

Dominion Experimental Sub-Station, Woodslee, Ontario

[Received for publication May 25, 1953]

ABSTRACT

The effects of two soil conditioners on some physical properties of a Brookston clay soil were studied during the 1952 and 1953 seasons. Formulation 931, a hydrolyzed polyacrylonitrile compound, incorporated at 0.10 and 0.05 per cent concentrations by disking and by rotary tillage, did not produce significant changes in the physical properties studied. Formulation 6, a modified vinyl acetate maleic acid compound incorporated by rotary tillage at 0.10 and 0.05 per cent concentrations, gave significant increases in aggregation, and in total and non-capillary pore space. These physical improvements in the surface 6-inch depth had no effect on corn yield where fertilizer was applied in 1952 and had no effect on yield in either the unfertilized or fertilized plots in 1953. Formulation 6 produced a significant depression in corn yield where no fertilizer was applied in 1952.

The recent development of soil conditioners on a commercial basis has caused widespread interest in the possibilities of improving clay and other fine-textured soils where physical condition is a limiting factor in the production of crops. Various studies (1, 7, 11) have indicated that some soil conditioners produced marked improvements in soil physical characteristics. Two of the more effective synthetics were a hydrolyzed polyacrylonitrile and a modified vinyl acetate maleic acid compound.

The present study was made to investigate the effects of these two soil conditioners on some physical properties of a Brookston clay soil when the materials were incorporated by two methods at two concentrations and in combination with fertilizer. A corn crop was grown to evaluate the effect of conditioners on yield.

Brookston clay is a member of the Brookston soil series (13), a series of wide distribution throughout Essex, Kent and Lambton counties in Ontario. The Brookston soils present certain problems in soil management. These problems are associated with poor physical condition resulting from fine texture, level topography and common cultural practices used for the production of cash crops in the district[5] (3, 6). Should soil conditioners be effective in improving the soil physical condition, it was considered that soil productivity would show concurrent improvement.

EXPERIMENTAL PROCEDURE

The two soil conditioners used in this study were a hydrolyzed polyacrylonitrile (Formulation 931) and a modified vinyl acetate maleic acid compound (Formulation 6). The test was made at the Woodslee Sub-Station on soil classified as Brookston clay (13). The area under study had been cropped to corn for the two years previous to 1952 and had grown alfalfa for two years preceding the corn. This area had grown many row crops before the Station was established in 1946.

[1] Contribution from the Experimental Farms Service, Department of Agriculture, Ottawa.
[2] Research Officer, Dominion Experimental Sub-Station, Woodslee, Ontario.
[3] Research Officer, Dominion Experimental Station, Harrow, Ontario.
[4] Officer-in-Charge, Dominion Experimental Sub-Station, Woodslee, Ontario.
[5] Annual Report (*unpublished data*) 1952. Dominion Experimental Sub-Station, Woodslee, Ontario.

A split plot, randomized block experiment having four replications, was used for the test in 1952. Table 1 gives the methods of incorporation and the concentrations of the two materials that were used in the test. Main plots for fertilizer treatments were 126 feet in length and 31 feet in width and were divided into nine sub-plots, each 31 feet long, for the purpose of conditioner application.

The area selected for the experiment was ploughed to a depth of 6 inches and subsequently cultivated with a disk harrow and packed with a 'cultipacker' to facilitate application of the amendments. Formulations 931 and 6 were applied to a 6-inch depth at 0.10 and 0.05 per cent concentrations, based on the dry weight (2,000,000 lb.) of soil to that depth. Since formulation 931 contained 25 per cent active ingredient, it was necessary to apply this material at four times the rate of Formulation 6 to provide a corresponding amount of active ingredient. Formulation 931 was incorporated by two methods, viz., by disking and by rotary tillage, for each concentration, while the two concentrations of Formulation 6 were incorporated by rotary tillage only. Control plots were included in the test for each of the tillage treatments.

A commercial fertilizer (10-10-10) was applied to one-half of each block at the rate of 700 lb. per acre. Following the application of conditioners and fertilizer, a crop of hybrid field corn was grown on the plots. The plots were fall ploughed in 1952. In the spring of 1953, fertilizer (10-10-10) was applied at the rate of 700 lb. per acre to those areas which had received this treatment in 1952 and another crop of corn was grown.

Samples for the aggregation study were taken by spade during August of 1952 and 1953 in the surface 6 inches, after a thin portion of the surface soil had been removed. Core samples, 3 inches in diameter and generally known as 'large cores', were taken from the surface 6 inches after a thin surface slice had been removed as for the aggregation samples. Low moisture conditions in 1952 and 1953 delayed large core sampling until the latter part of each growing season.

Aggregation was determined by the Yoder (14) wet sieving technique using material which had passed through a one-half inch screen. The results were expressed as coefficients of aggregation (9).

Total porosity was determined from the volume weights of the cores (5). Non-capillary pore space, considered to be the volume fraction important in soil aeration, was determined by the Leamer and Shaw method (10). Capillary porosity was calculated as the per cent water remaining in the cores after a pF of 1.6 had been applied to the saturated cores for twelve hours.

Moisture equivalents were determined on composite samples from each subplot by the Briggs and McLane (4) method. The maximum water-holding capacity was measured on these samples by Hilgard's (8) method. Permanent wilting points were also determined on these composite samples by means of the pressure-membrane extraction apparatus as outlined by Richards and Weaver (12).

Corn yields were reported in bushels per acre of shelled corn at 15 per cent moisture.

The data were treated statistically to test for differences between treatments and to determine the effects from fertilizer and combined action of fertilizer with conditioners. The corn yield data for the fertilized main plots were separated from the non-fertilized data and these results were analysed separately as in a randomized block experiment.

RESULTS AND DISCUSSION

Both concentrations of Formulation 6 displayed a marked effect in stabilizing the surface soil crumbs. Following 1.33 inches of rain during the last week of May, 1952, it was observed that Formulation 6 was much more effective in maintaining crumb stability than was Formulation 931. Formulation 931 did not produce visible improvement in crumb stability over that of the control plot. Plots treated with Formulation 931 appeared to retain more moisture at the surface, a fact which may have accounted for the abundant weed emergence in these plots in comparison with weed growth on the controls and in plots treated with Formulation 6. In mid-growing season of 1952 the plots treated with Formulation 6 remained quite loose and friable, whereas Formulation 931 produced little or no change over the control plots, which appeared highly compacted. The favourable appearance of plots treated with Formulation 6 persisted through the winter and spring of 1953 and was in evidence throughout the 1953 growing season.

The quantitative results for aggregation and yield of corn are presented in Table 1.

In 1952, Formulation 6 at 0.10 per cent concentration increased the coefficient of aggregation to a highly significant degree as compared with all other treatments. The lower concentration (0.05 per cent) of Formulation 6 increased the coefficient of aggregation significantly as compared with its control plot, but the increase was not significant as compared with any other treatment. The results with Formulation 931 suggested that this material tended to improve aggregation, but none of the differences attained statistical significance.

The differences in aggregation were less in 1953 than in 1952. Nevertheless, Formulation 6 at 0.10 per cent concentration continued to maintain a level of aggregation significantly higher than that given by any other treatment, with the exception of Formulation 931 disked into the soil at the level of 0.10 per cent. Both concentrations of Formulation 6 maintained a significant improvement in aggregation over the control plots and over the low concentration of Formulation 931 incorporated by rotary tillage.

Precipitation during the growing seasons of 1952 and 1953 was much lower than the average for the preceding five years. During the previous five years the average amount of rainfall from May to September inclusive was 15.09 inches, while totals of 9.36 and 9.40 inches were recorded during these months in 1952 and 1953 respectively. Weather conditions in both years were considered favourable for corn production. However, it is possible that more rainfall might have resulted in a favourable effect of the conditioners on yield.

TABLE 1.—EFFECT OF TWO SOIL CONDITIONERS ON SOIL AGGREGATION AND YIELD OF CORN ON BROOKSTON CLAY

Treatment	Per cent concentration[1]	Coefficient of aggregation[2]		Corn yield in bushels per acre			
				1952		1953	
		1952	1953	No fert.	Fert.	No fert.	Fert.
			Disked				
Formulation 931	0.10	656	490	54.3	65.4	33.8	54.4
	0.05	521	447	50.5	63.3	30.6	56.2
	0	490	427	53.8	61.5	34.2	53.1
			Rotary tilled				
Formulation 931	0.10	851	481	54.7	68.8	27.2	50.1
	0.05	550	413	52.3	64.4	29.1	54.2
Formulation 6	0.10	2048	583	46.4	62.0	33.8	57.6
	0.05	1024	526	46.2	63.4	35.1	55.1
	0	441	422	53.9	60.7	34.5	52.8
L.S.D. 0.05	—	549	95	5.0	N.S.	N.S.	N.S.
0.01	—	747	129	6.8	N.S.	N.S.	N.S.

[1] Concentration of active ingredient as per cent of soil.
[2] Average values for fertilized and unfertilized plots.

As shown in Table 1, the application of conditioners did not increase the yield of corn in either year. In 1952, both concentrations of Formulation 6 resulted in a decreased yield in the absence of fertilizer. Where fertilizer was applied, however, the conditioner treatments did not affect corn yield.

The total porosity values appear in Table 2. These values were calculated from the volume weights of large core samples.

In 1952 both concentrations of Formulation 6 gave a highly significant improvement in per cent total porosity over the rotary-tilled check. Formulation 931, when incorporated by rotary tillage at the 0.10 per cent concentration, increased total pore space to a highly significant level over the check plot; and when applied at the 0.05 per cent concentration, Formulation 931 increased total pore space to a significant level over the check plot.

In 1953, Formulation 6 maintained per cent total pore space at a highly significant level over the control plot. Of the Formulation 931 treatments, only the 0.05 per cent concentration of this conditioner altered total pore space in 1953. This concentration, incorporated by disking, increased total pore space to a highly significant level over all other Formulation 931 treatments, a result for which there was no apparent explanation.

TABLE 2.—EFFECT OF TWO SOIL CONDITIONERS ON PER CENT TOTAL, NON-CAPILLARY, AND CAPILLARY POROSITIES OF BROOKSTON CLAY

Treatment	Per cent concentration[1]	Per cent total porosity[2]		Per cent non-capillary porosity[3]		Per cent capillary porosity[3]	
		1952	1953	1952	1953	1952	1953
			Disked				
Formulation 931	0.10	56.2	53.3	15.1	10.8	38.2	37.8
	0.05	55.7	56.2	17.7	14.1	36.9	36.2
	0	54.9	54.0	15.6	11.5	36.7	36.4
			Rotary tilled				
Formulation 931	0.10	57.6	53.9	18.3	12.5	36.8	36.4
	0.05	57.1	53.8	16.1	11.8	36.7	36.3
Formulation 6	0.10	58.0	57.6	26.0	19.4	31.4	33.6
	0.05	57.4	56.7	22.5	17.6	33.3	34.1
	0	54.8	54.1	18.3	11.9	35.9	37.1
L.S.D. 0.05	—	1.7	1.4	4.3	1.6	2.2	1.0
0.01	—	2.4	1.8	5.8	2.2	2.9	1.3

[1] Concentration of active ingredient as per cent of soil.
[2] Average values for fertilized and unfertilized plots, calculated from volume weights of large cores.
[3] Average values for fertilized and unfertilized plots, measured by Leamer and Shaw method.

The porosity measurements as determined by the method of Leamer and Shaw are shown in Table 2.

In 1952, the high concentration of Formulation 6 increased non-capillary porosity to a highly significant level over all other treatments except the 0.05 per cent concentration of this conditioner. In 1953, both concentrations of Formulation 6 maintained non-capillary pore space at a highly significant level over all other treatments. The 0.05 per cent concentration of Formulation 931 also gave a highly significant increase in non-capillary porosity in 1953.

Capillary porosity results in 1952 and 1953 indicated that both concentrations of Formulation 6 significantly reduced the capillary pore space. The simultaneous reduction in capillary pore space and increase in non-capillary porosity would suggest that non-capillary pore space was increased at the expense of the capillary pore space.

In this experiment the conditioners brought about little or no change in maximum water-holding capacity, moisture equivalent, or permanent wilting point as evidenced in Table 3. It will be noted that the moisture equivalent for all applications of Formulation 931 was significantly different from that obtained for Formulation 6 at the high concentration. However, none of the treatments resulted in a moisture equivalent significantly different from that of the checks. The maximum water-holding capacities

TABLE 3.—EFFECT OF TWO SOIL CONDITIONERS ON PER CENT MAXIMUM WATER-HOLDING CAPACITY, MOISTURE EQUIVALENT AND PERMANENT WILTING POINT OF BROOKSTON CLAY

(Average values for fertilized and unfertilized plots.)

Treatment	Per cent concentration[1]	Per cent maximum water-holding capacity	Per cent moisture equivalent	Per cent permanent wilting point	Per cent field moisture		
					1952		1953
					After rain	After dry week	After dry week
			Disked				
Formulation 931	0.10	64.09	27.97	15.72	—	—	20.20
	0.05	63.69	27.84	15.97	—	—	18.08
	0	59.98	27.10	15.21	24.03	18.12	18.60
			Rotary tilled				
Formulation 931	0.10	63.22	27.64	14.92	26.18	19.59	20.55
	0.05	61.19	27.56	15.55	24.91	18.83	19.89
Formulation 6	0.10	62.54	26.38	15.16	26.02	19.86	19.73
	0.05	61.88	26.61	15.13	25.15	18.96	19.03
	0	61.41	27.29	15.51	24.61	18.77	18.71
L.S.D. 0.05	—	N.S.	1.00	N.S.	1.56	1.01	N.S.
0.01	—	N.S.	1.36	N.S.	2.08	1.35	N.S.

[1] Concentration of active ingredient as per cent of soil.

of the plots appeared to show a trend in favour of conditioners, especially where the materials were applied at the 0.10 per cent concentration.

The field moisture test, carried out on certain plots during the 1952 growing season, was an attempt to measure the amount of moisture retained in the soil after a moderate rain and again after a week of intense drying conditions which followed the rain. Plots treated with the 0.10 per cent concentration of either Formulation 931 or Formulation 6 retained slightly more moisture after the rain and also following a dry week. Moisture determinations carried out on the plots following a dry period in 1953 yielded results similar to those obtained in 1952.

Only Formulation 6, the modified vinyl acetate maleic acid compound, produced and maintained significant increases in properties associated with soil physical improvement. The improvement in the surface 6-inch depth had no effect on corn yield where fertilizer was applied in 1952, and had no effect on yield in either the unfertilized or fertilized plots in 1953. On the other hand, Formulation 6 produced a significant depression in corn yield where no fertilizer was applied in 1952. These results may have been influenced by the two unusually dry seasons, and by the fact

that the conditioning materials were incorporated in only the surface 6-inch depth. Previous work (2) has indicated the existence of a compacted layer at the 6-12 inch depth in Brookston clay which may limit the effects of treatments designed to improve only the surface layer of soil.

Aggregation by Formulation 6 was considerably less in 1953 than in 1952. This was the only measurement obtained in this study which would indicate a deterioration in the effect of this soil conditioner. The decrease in aggregation may have been influenced by additional mixing of the surface 6 inches of soil in the plots in 1953.

The present results suggest the desirability of extending these studies to include such factors as depth of placement, effects on different crops, and persistency of the effects on structural properties of the soil.

ACKNOWLEDGEMENTS

The authors extend thanks to the Monsanto Chemical Company for supplying the materials which made this study possible and are especially indebted to Norman Smith, of the Monsanto Chemical Company, who devoted much time and effort in establishing the experiment. The authors wish to acknowledge the active assistance and helpful suggestions given by H. F. Murwin, Superintendent of the Dominion Experimental Station, Harrow, Ont. Thanks are also extended to N. R. Richards and L. R. Webber of the Soils Department, Ontario Agricultural College, Guelph, Ont., for making available equipment used in the moisture investigation. The authors also wish to thank members of the Division of Field Husbandry, Central Experimental Farm, Ottawa, for reviewing the manuscript.

REFERENCES

1. Allison, L. E. Effect of synthetic polyelectrolytes on the structure of saline and alkali soils. Soil Sci. 73 : 443-454. 1952.
2. Bolton, E. F. A study of effects of certain cropping systems on some physical properties of a Brookston clay soil. Thesis, University of Toronto. 1951.
3. Bolton, E. F., and L. R. Webber. Effect of cropping systems on the aggregation of a Brookston clay soil at three depths. Sci. Agr. 32 : 555-558. 1952.
4. Briggs, L. J., and J. W. McLane. The moisture equivalent of soils. U.S.D.A. Bur. Soils Bull. 45. 1907.
5. Coile, T. S. Soil samplers. Soil Sci. 42 : 139-142. 1936.
6. Fulton, J. M. The effects of a number of three-year rotations on some of the physical properties of the Brookston clay and a correlation of these with yield of hybrid corn. Thesis, University of Toronto. 1952.
7. Hedrick, R. M., and D. T. Mowry. Effect of synthetic polyelectrolytes on aggregation, aeration, and water relationships of soil. Soil Sci. 73 : 427-441. 1952.
8. Hilgard, E. W. Soils. The Macmillan Company, New York. 1906.
9. Johnston, J. R., G. M. Browning, and M. B. Russell. The effect of cropping practices on aggregation, organic matter content, and loss of soil and water in the Marshall silt loam. Soil Sci. Soc. Amer. Proc. 7 : 105-107. 1943.
10. Leamer, R. W., and B. Shaw. A simple apparatus for measuring non-capillary porosity on an extensive scale. J. Am. Soc. Agron. 33 : 1003-1008. 1941.
11. Martin, W. P., G. S. Taylor, J. C. Engibus, and E. Burnett. Soil and crop responses from field applications of soil conditioners. Soil Sci. 73 : 455-471. 1952.
12. Richards, L. A., and L. R. Weaver. Fifteen atmosphere percentage as related to the permanent wilting percentage. Soil Sci. 56 : 331-339. 1943.
13. Richards, N. R., A. G. Caldwell, and F. F. Morwick. Soil Survey of Essex County. Report 11, Ontario Soil Survey. 1949.
14. Yoder, R. E. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. J. Am. Soc. Agron. 28 : 377-351. 1936.

TECHNIQUES FOR ROOTING CUTTINGS, CHROMOSOME DOUBLING AND FLOWER EMASCULATION IN ALFALFA

KARLIS LESINS[1]

Department of Plant Science, University of Alberta, Edmonton, Alta.

[Received for publication July 12, 1954]

ABSTRACT

For rooting alfalfa cuttings the application of 350 p.p.m. naphthalene acetic acid in talc, followed by culturing the treated cuttings in embedding medium made of 1 part sand plus 1 part sphagnum peat by volume, has given good results.

Duplication of the chromosomal set may be successfully achieved by soaking seedlings in an inverted position in 0.07 per cent aqueous colchicine for 6 hours at room temperature. A similar procedure may be applied to rooted cuttings.

Efficient emasculation may be effected by immersing opened flowers for 4 to 6 seconds in 57 per cent alcohol followed by soaking in water for 15 to 30 minutes. Anthers may be removed by sharp blasts of breath instead of suction by air nozzle.

The author, working during the past 10 years on different alfalfa improvement projects, has found it necessary to modify some of the procedures used in alfalfa breeding[2]. These improved techniques may also be of interest to other workers engaged in alfalfa as well as in breeding work of other legume crops.

ROOTING ALFALFA CUTTINGS

Healthy, vigorous alfalfa plants taken from field during the first part of summer yield cuttings which root fairly well without any artificial root-stimulating treatments. It is different, however, in fall and winter under greenhouse conditions. There, rooting is often unsatisfactory and means should be found to safeguard against devastating losses in cutting material.

Several authors (1, 9, 10, 11) have reported better rooting on application of root-inducing substances. Their results indicate that 1-naphthalene acetic acid (NAA) has been superior to other substances tested. Concentrations recommended have been 5 to 100 p.p.m. on soaking basal ends of cutting for 12-24 hours in water as the carrier of the active substance. Soaking in water, however, has several disadvantages. The solution should be prepared every time anew; the concentration should be kept within narrow limits in order to avoid injuries; transplanting of the treated cuttings cannot be postponed even if for weather conditions or other reasons it would be advisable; most of all, special, not easily handled, trays and racks are needed, and considerable additional work is required for this treatment. For these reasons other carriers used on different other plant species (2, 12) and in a preliminary report mentioned also for alfalfa (10) seemed to be more promising. Commercial talc powder as

[1] Research Associate in Forage Crops.

[2] Work at the Swedish Seed Association Branch Station, Ultuna, 1945-51, has been aided partly by the Wenner-Grens foundation; at the University of Alberta, 1952-54, by the National Research Council of Canada.

an easily available material was decided upon. This carrier eliminates nearly all of the disadvantages connected with the soaking method. Once prepared, the mixture is ready for use when needed; the treatment may be applied just at the time of planting; no special tools are necessary; very little additional work is needed, and it may be carried out by inexperienced personnel; concentration of the active substance may vary within much wider limits than in water solution. In the present author's experiments, concentrations of 250 and 500 p.p.m. both tended to give uniformly good results and were about equally effective; therefore, for practical use, concentration midway of these, i.e., 350 p.p.m., was chosen.

In propagation of plants by cuttings, one more item, that of embedding medium in which cuttings have to be raised until rooted, is of importance. Sand is commonly used as embedding medium and gives good results, provided drying out can be prevented. After some losses had been suffered in its practical application a more stable medium regarding moisture content was selected. It consisted of 1 part sand to 1 part of sphagnum peat by volume. Hitchcock (3) has tried this medium on different plant species and found it useful for most of the species which root well in sand.

A method of improved rooting without application of root promoting substances has been reported by White (15). It consists in culturing cuttings during root development in running water. This technique requires special greenhouse equipment and, while found effective in some institutions, it has not given satisfactory results in others, for instance, at Ultuna, Sweden. The reason for such discrepancy may be related to differences in content of oxygen and other solutes in waters (from wells or rivers) used at different places.

The following schedule for rooting alfalfa cuttings is now in use and giving consistently good results:

1. *Stems are cut in one-node cuttings 3 to 5 cm. below and 1 cm. above the node.*

Cuttings from healthy, vigorous plants root better than those of less vital individuals. Stems not undergoing terminal growth rarely give rooted cuttings; therefore, plants that have not yet reached flowering stage are the best cutting material. The middle portion of the stems gives the strongest cuttings though apical and lower nodes may be utilized too.

2. *Cuttings are gathered in bunches of 5 to 10 pieces and dipped with their lower ends first in water, then in talc to which 350 p.p.m. of NAA has been added.*

Talc-NAA mixture is easily prepared as recommended by Stoutemyer (12). For instance, to make 100 gr. of powder: 35 mg. of 1-naphthalene acetic acid are dissolved in 90 to 100 ml. of ethyl alcohol and poured on to 100 gr. of talcum powder to make a pasty mixture. This is dried at room temperature and stirred occasionally. When dried and kept in a stoppered container in the dark, it has not shown deterioration after more than two years of storage.

3. *Cuttings are planted 3 to 4 cm. deep into trenches of embedding medium, consisting of 1 part sand and 1 part peat by volume.*

A medium coarse sand and sphagnum peat are used; both materials sifted in order to secure a smooth sided trench. After both constituents have been thoroughly mixed water is applied to full saturation, which

ensures sufficient moisture during the first few days after planting. The trench is made with a strip of sheetmetal and, after placing the stems of the cuttings against one of the walls, the trench is closed tightly by pressing the embedding material from the opposite wall against the stems with the same tool.

4. *The flats with cuttings are kept at temperature preferably not below 20° C. In fall and winter additional light is supplied to make 16 hours' illumination daily. Watering is given when the surface crumbs of sand-peat mixture show signs of drying.*

Air temperatures higher than 20° C. and up to 30° C. provide for quicker rooting. Some observations on the duration of illumination indicate that continuous light has at least no harmful effect. During the first two or three days, the cuttings are lightly sprinkled with water; a heavy watering might displace the growth substance from the ends of the cuttings. The phenomenon reported by Grace (2), that hormone-treated materials retain their turgor while the untreated cuttings wilt more readily, has also been observed in alfalfa as shown in Figure 1. This difference remains during the whole rooting period.

5. *After 3 weeks, cuttings may be transplanted to the nursery or greenhouse bed.*

From time to time the efficiency of the above schedule has been checked against untreated material under diverse experimental conditions. Table 1 presents the results obtained.

Conditions at which trials were run have been as follows:

Trial A was conducted in greenhouse at Ultuna, May 24-June 14, 1948, at temperature 20-30° C., at natural day length. 15 cuttings were taken for treatment and check of each plant.

Trial B—In growth chamber at Ultuna, November 6-November 29, 1948; temperature 19-21° C.; artificial light (only) for 16 hours daily; 10 cuttings for treatment and check of each plant.

Trial C—In greenhouse at Edmonton, November 7-November 27, 1952; temperature 18-21° C., natural day length supplemented in evenings by artificial light to 16 hours daily. In this latter trial, all other potential sources of variability such as peat, sand, water and chemicals, have been of different origin than in the previous two.

As shown in Table 1, treatments in all trials have given highly satisfactory results. Under less favourable temperature and light conditions, as in trials *B* and *C*, the response of rooted cuttings to treatment has been comparatively more expressed; but also, under the more favourable conditions in trial *A*, an increase by 30 per cent is distinctly suggestive of the usefulness of the treatment.

Nilsson and Andersson (9) and White (15) observed that there were differences among plants in their rooting capacity. This also occurred in the material reported above. In trial *A*, plant 109-4-2 was the lowest in root formation, plant 141-4-1 though of good rooting capacity clearly did not respond to the growth substance, and 108-3-4 gave a high rooting with treatment and a poor one without it. The experiment with these three plants was repeated later in the summer (June 17-July 6). The rooting percentages in treated-check were: 0-0, 67-67, and 80-47 for the respective plants, and thus in fair agreement with the previous findings.

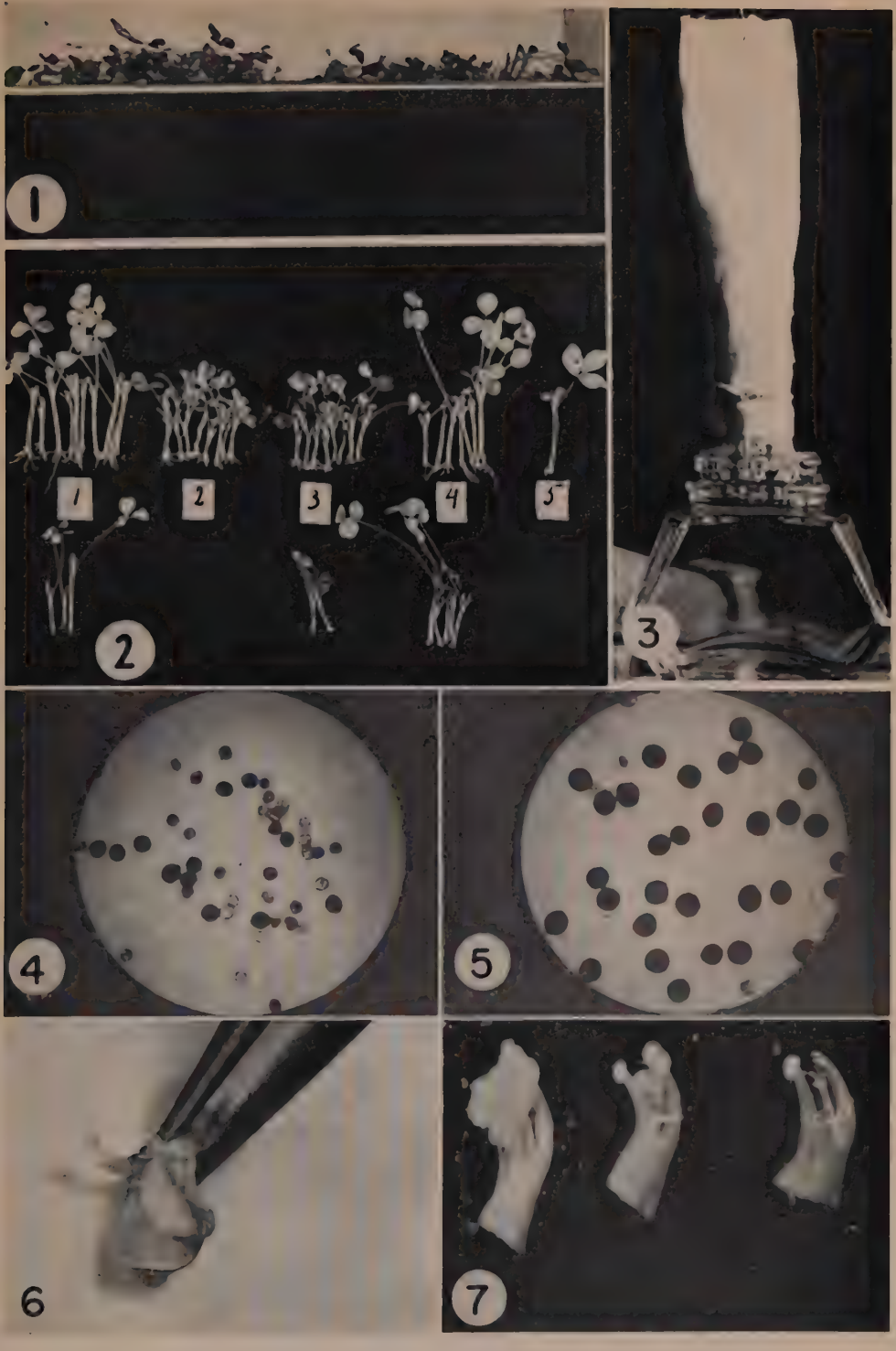

FIGURE 1, *left*—NAA treated cuttings showing less wilting than untreated on *right*.

FIGURE 2, *upper row*—better rooting of cuttings due to NAA treatment, *lower row*—untreated.

FIGURE 3. Setup for immersion of seedlings in colchicine solution.

FIGURE 4. Pollen grains from a flower of a triploid, 3x = 24, cutting.

FIGURE 5. Pollen grains of a chromosome doubled flower from the same raceme as in Fig. 4, both at same magnification.

FIGURE 6. Releasing the staminal column from keel without stigma hitting the tweezers.

FIGURE 7, *left*—staminal column before blowing off the anthers; *centre* anthers partially blown off; *right*—all anthers removed.

TABLE 1.—PERCENTAGE OF ROOTED CUTTINGS INDUCED BY TREATMENT WITH 350 P.P.M. NAA IN TALC AS COMPARED TO UNTREATED

Plant No.	Per cent rooted cuttings		Plant No.	Per cent rooted cuttings	
	Treated	Untreated		Treated	Untreated
Trial A					
108–3–4	93	13	120–2–5	100	53
108–5–2	93	80	141–4–1	67	87
109–4–2	40	13	148–2–2	73	60
112–5–1	60	13	150–4–3	80	80
123–2–3	93	33	153–2–5	53	33
127–3–3	100	67	157–1–3	100	80
127–4–4	93	33	159–5–5	93	67
130–3–4	100	80	187–3–3	100	47
135–1–1	100	53	192–3–4	100	40
135–1–2	93	40	198–2–1	100	87
Per cent rooted per trial				86.5	53.0
Trial B					
135–4–4	50	30	201–5–4	70	10
134–4–5	90	10	186–4–2	70	30
121–4–1	60	20	172–4–3	90	20
121–2–3	60	10	185–2–1	90	10
124–1–3	40	0	156–5–5	90	10
117–5–5	0	0	133–2–2	40	0
134–1–3	100	10	211–2–5	60	0
119–3–5	50	0	226–5–3	40	0
128–3–2	20	0	229–2–1	40	10
136–2–2	70	10	213–3–3	60	0
Per cent rooted per trial				59.5	9.0
Trial C					
1	83	25	4	58	42
2	67	0	5	8	0
3	67	17			
Per cent rooted per trial				56.6	16.8

Applications of NAA not only increase the number of rooted cuttings but also produce better developed and more abundant roots, as exemplified by *Trial C* given in Figure 2.

DUPLICATION OF THE CHROMOSOME COMPLEMENT

Chromosome duplication of the diploid, 2n = 16, *Medica gosativa* and *M. falcata* strains removes the ploidy barrier existing between these and the cultivated alfalfa, (7). Some of the diploid strains possess valuable characters, such as extreme winter hardiness or high resistance to bacterial wilt (8). Duplication of the chromosomal set is a necessary step in transferring these desired characters to cultivated material by hybridization. Duplication of chromosomes of cultivated alfalfa is also of some interest in the study of plant behaviour at chromosome levels higher than tetraploid.

The method described by Johnson and Sass (4) for inducing tetraploidy in *Melilotus* was adapted for alfalfa. Some changes as to concentration of the colchicine solution and treatment of seedlings before and after the application of colchicine have been found advantageous. Other methods such as imbibition of colchicine by placing pieces of moistened cotton, drop of agar or tragacanth between cotyledons, or needle injection have been found less efficient because of time and labour required for treating seedlings individually. The procedure now in use is as follows:

1 *Seeds are germinated in Petri dishes until seedlings are about 2 cm. long.*

In order to get straighter growing seedlings the seeds may be sown in a dish with sand and covered with a 0.5 cm. layer. The younger the stage at which seedlings are subjected to colchicine treatment, the better are the chances that the entire top growth of a plant will be chromosome-doubled. Seedlings in which a certain differentiation of plumule cells has been completed do not show chromosome doubling in the main stem; sometimes, however, side branches are found doubled.

2. *Seed coats adhering to cotyledons are removed and seedlings placed on a filter paper strip about 10 cm. wide and full-sheet long soaked with water. The seedlings are oriented on the strip with the roots on the paper, while the hypocotyls are placed parallel to one another about 1.5 cm. apart and protruding over the paper edge.*

3. *The strip with seedlings is rolled up.*

Care should be taken in rolling to make the edge of the roll, where seedlings are situated in one plane so that all seedlings may be evenly immersed. If two hypocotyls happen to be so close together that the colchicine solution is likely to ascend by capillarity to the filter paper, one of the seedlings should be clipped off.

4. *The roll is hung, hypocotyls down, over a container in such a manner that there is a space of 3 to 5 mm. between the rim of the container and the filter paper, as shown in Figure 3.*

5. *The container is filled with 0.07 per cent aqueous colchicine. Cotyledons and a large part of each hypocotyl remain immersed for 6 hours at room temperature.*

The colchicine solution is prepared by dissolving the appropriate quantity of colchicine in the smallest possible volume of ethyl alcohol, then distilled water is added to obtain the required dilution. The container is first filled partly with colchicine solution, the roll levelled at the right height, then the container is filled up to the brim with a pipette. Some replenishing of the solution may be needed in the later part of the immersion period. Regarding temperature, it has been observed that on hot summer days the seedlings are more perceptibly affected than on days of moderate room temperature.

6. *The roll with seedlings is unwrapped; the seedlings are placed in a dish of tap water and kept there overnight.*

Washing seedlings overnight in water, instead of only rinsing them after colchicine treatment, restores their full turgidity and leads to better survival.

7. *Next day, seedlings are planted up to the cotyledons in thoroughly moistened soil to which some peat has been admixed.*

Packing wet soil close up to cotyledons is of importance as the hypocotyls seem to be most affected by colchicine treatment and often wilt if after transplanting they are exposed to the air. On a few occasions it was even observed that adventitious roots were formed on hypocotyls close to cotyledons.

The per cent of survival after careful planting was 85, 94 and 91 in three different trials, counted two months after treatment.

The chromosome-doubled stems, as compared with normal stems, appear more robust; the leaves are thicker and more deeply toothed; the flowers somewhat larger, especially the calyx which is thicker. The most dependable indication of chromosome doubling, however, is provided by increased size of the pollen grains. Those of natural diploids and natural tetraploids average 35μ and 38μ in diameter while chromosome duplicated materials show average diameters 43μ and 47μ respectively.

On some occasions, after colchicine treatment as described above, records were kept on the number of plants that showed chromosome duplication as indicated by the size of the pollen grains. These data are presented in Table 2.

As seen in Table 2, good results have been obtained from treatment in every case. The differences in percentages for different materials are likely caused for the most part by factors other than the inherent plant response. The 2n = 32 material, for instance, was planted outdoors, where it did not come to flower during the first year. Pollen testing was, therefore, based on second-year growth, in which some of the chromosome-doubled shoots may not have reappeared as the result of competition with normal shoots. *M. sativa*, 2n = 16, on the other hand, was grown in the greenhouse; each plant was scrutinized several times and doubled shoots were discovered on new plants on successive examinations. Also, differences in room temperature during various treatments may have affected the results.

Duplication of the chromosome set in shoots of cuttings is done in a similar way. Well rooted cuttings about 15 cm. of top growth, or top growth cut back to that length, are removed from the soil, preferably by washing with a water stream in order to preserve the root system. Roots

TABLE 2.—NUMBER AND PER CENT OF PLANTS SHOWING CHROMOSOME DUPLICATION AFTER COLCHICINE TREATMENT

Materials treated	Number of plants grown	Plants with chromosomal duplication	
		No.	Per cent
M. falcata 2n = 16, 8 lots	217	31	14
M. sativa 2n = 16, 3 lots	137	54	39
M. falcata 2n = 32, 1 lot	15	2	13
M. sativa 2n = 32, 10 lots	243	27	11
Weighted average	—	—	18.6

are wrapped in moist cotton to prevent drying during the treatment. Tops are immersed downward up to the roots in a colchicine solution of the strength and for the time indicated for seedlings. After thorough washing and planting in moist, peat-enriched soil no wilting of the top growth should take place. Individually potted cuttings possibly may give good results if inverted over a beaker of colchicine in a manner similar to that described by Johnson and Holtz (5).

In distinction to seedlings, in which entire shoots are often found to be chromosome-doubled, the shoots of cuttings are most often chimerical, with streaks of doubled tissue running along the stems. In the same raceme chromosome-doubled and non-doubled flowers may be found. Figure 4 shows pollen grains of a flower from a colchicine treated triploid cutting; Figure 5 pollen grains of another flower of the same raceme. In this latter case, the larger and better pollen grains are obviously due to doubling of the chromosomal set. Entire chromosome-doubled branches seem to be less frequent than with seedlings; on one recorded occasion there were such entire branches on 3 out of 32 treated cuttings.

EMASCULATION OF FLOWERS

Tysdal and Garl (14) introduced the method of emasculation by immersion of opened flowers for 10 seconds in 57 per cent ethyl alcohol solutions. Working for some time with the original method, some shortcomings were noted. First, anthers remaining around the stigma of treated flowers were a hindrance to the application of foreign pollen, especially if only a small number of pollen-bearing flowers were available for pollinating. Secondly, immersion for 10 seconds in 57 per cent alcohol, while non-injurious to some plants, seemed to reduce severely the fertility in others.

In order to remove anthers and loose pollen, air suction has been used by some investigators. However, under field conditions, in which such suction could not be easily applied, it was discovered that blowing sharp blasts of breath was an effective means of cleaning the stigmas. After this practice was mastered, there was no need to resort to suction under any conditions. This is now considered to be the superior method, since the nozzle of the suction apparatus may be a source of injury and contamination to the stigmas.

As a safeguard against injuries from immersion for 10 seconds in 57 per cent alcohol it was found possible to reduce this time by half and combine it with emasculation by water. The schedule for crossing plants now in use is as follows:

1. *Standards are cut off on a number of flowers intended for crossing.*

Standards are cut off with small, sharp scissors so that stigmas and upper part of staminal columns (after they have been released from keels) lie free over the cut edge of the standards. Flowers which trip while cutting the standards, and stigmas that hit the scissors, are better clipped off as their own pollen may be pressed deeply into the wounded surface of stigmas and be difficult to destroy in further treatment.

2. *Staminal columns of the flowers of one of the racemes are released from the keels.*

The release of the staminal column from the keel is done by pressing the flower part with tweezers just below the cut edge of the standard, and preventing the stigma striking the tweezers. (See Figure 6).

3. *The raceme is immersed in 57 per cent alcohol in one to three quick movements.*

The time during which alcohol is in contact with the flower will total 4 to 6 seconds, that is, while making the few quick movements of the raceme in the beaker of alcohol, and while putting this beaker down and lifting up the beaker with water.

4. *The alcohol-treated raceme is immersed in water and washed for 10 to 20 seconds. When taken out, it is left without shaking off the water until other racemes are run through Steps 2 and 3.*

The water adhering to the flowers, after the raceme has been taken from the beaker, will not dry off until 8 to 10 further racemes are treated. Thus, water remaining on flowers for 15 to 30 minutes will continue to destroy pollen which may have escaped the alcohol treatment. The damaging effect of water to alfalfa pollen has been demonstrated by Torssell (13). Without previous immersion in alcohol, however, water does not wet flowers thoroughly. Another advantage of the water film is that pollen scattered about from released columns of other racemes will not come in direct contact with the stigmas. If more than 10 racemes are manipulated as one set, some racemes may need repeated immersion in water to keep them moist.

5. *Now the first of the treated racemes is held by its stalk with the left hand against the palm of right hand and sharp blasts of breath are directed at different angles by slightly turning the stalk until all stigmas are free from anthers.*

Hands and tools should be cleaned in alcohol before commencing this step.

There are differences among plants regarding tenacity by which anthers are held by their filaments. In some cases single anthers may have to be picked away by fine-pointed tweezers after the anthers have been bent off the stigma by sharp blasts of breath.

Plants with easily-breakable pedicels are also encountered. In such cases loss of a number of flowers when blowing off anthers is inevitable. When handling rather self-fertile plants it is advisable to rinse the hands with alcohol before taking up a next raceme. Figure 7 shows staminal columns before and after anthers have been blown off.

6. *Pollen is applied with a toothpick to stigmas; the raceme is tagged and protected by a light paper (a very light-weight envelope or a wrapping of toilet tissue) fastened over it. Other racemes are taken in turn through Steps 5 and 6.*

Isolation coverings are kept on racemes for a few days in order to avoid contamination by air-borne foreign pollen while stigmas are still susceptible to fertilization.

TABLE 3.—EFFICIENCY OF EMASCULATION AS INDICATED BY SEED SET WHEN EMASCULATION WAS FOLLOWED BY NON-POLLINATION, CROSS-POLLINATION OR INCOMPATIBLE POLLINATION.

Maternal plants	Pollen source	No. of flowers tested	No. of seeds set	No. of seeds per 100 flowers
217-6BI-65, diploid	None	97	1	1.0
217-6BI-65, diploid	Foreign diploid	621	713	114.8
R7-U3, tetraploid	None	106	1	0.9
R7-U3, tetraploid	Foreign tetraploid	112	114	128.6
Several plants, tetraploid	Diploid	1420	8	0.6

With this procedure it takes about 3/4 to 1 hour to emasculate, cross, tag and isolate 100 flowers.

Efficient emasculation involves: (a) the devitalization or removal of own pollen grains before any pollen tubes have penetrated the stigma of the flower; and (b) the avoidance of damage to the pistil from the manipulations of emasculation. Data regarding fulfilment of these requirements are given in Table 3.

As may be computed from Table 3 the weighted average seed set has been only 0.6 seeds per 100 flowers when emasculation was not followed by any pollination or when incompatible pollen was used. In the latter case an investigation of the resulting 8 plants showed that 2 of them were triploids ($3x = 24$), and 2 more could be identified as hybrids by their flower colour, an indication that unreduced microspores of diploid yellow flowered alfalfa used as the pollen source have accomplished fertilization. Thus, out of 8 plants, only 4 or 0.3 seeds per 100 flowers may be ascribed as escapes at emasculation. According to the above results a very effective removal of own pollen grains has been achieved. However, in critical crossing work it should be remembered that, apart from accidental contamination after emasculation, there may be a few flowers which set seed without tripping (6), that is, some of such flowers may have been fertilized before emasculation.

The seed set of somewhat more than 100 seeds per 100 flowers when emasculation was followed by compatible cross-pollination is quite satisfactory for any crossing purpose even if some reduction in fertility may have taken place due to emasculation. Triploids and hybrids obtained at pollination of emasculated tetraploid flowers by pollen of diploid plants also indicate that the viability of ovules has not been impaired. Again, it should be remembered that many different factors may influence the seed set after emasculation and pollination. The health and state of development of maternal plants, also different external factors such as temperature and air humidity, as well as quality and affinity of pollen used for pollination may be decisive. The above ratio of about 100 seeds per 100 flowers may be considered as an average result. Seed set ranging from only a few seeds to as high as 470 per 100 flowers has been noted on different occasions.

REFERENCES

1. Burton, G. W. The stimulation of root formation on alfalfa cuttings. J. Am. Soc. Agron. 28 : 704-705. 1936.
2. Grace, N. H. Physiologic curve of response to phytohormones by seeds, growing plants, cuttings and lower plant forms. Can. J. Res., *C*, 15 : 538-546. 1937.
3. Hitchcock, A. E. Effect of peat, moss and sand on rooting response of cuttings. Bot. Gaz., 86 : 121-148. 1928.
4. Johnson, T. J., and J. E. Sass. Self- and cross-fertility relationships and cytology of autotetraploid sweet clover, *Melilotus alba*. J. Amer. Soc. Agron. 36 : 214-227. 1944.
5. Johnson, L. P. V., and H. W. Holtz. Colchicine treatment techniques for sprouted seeds and seedlings. Can. J. Res., *C*, 24 : 303-304. 1946.
6. Lesins, K. Investigations into seed setting of lucerne at Ultuna, Sweden, 1945-1949. Ann. Royal Agr. College of Sweden, 17 : 441-483. 1950.
7. Lesins, K. Some data on the cytogenetics of alfalfa. J. Hered. 43 : 287-291. 1952.
8. Lesins, K. Susceptibility of some diploid alfalfas to bacterial wilt. Agron. J. 46 : 251-252. 1954.
9. Nilsson, F., and E. Andersson. Några växthormoners inflytande på ulvecklingen av rödklöver—och blålucern—sticklinger. Nord. Jordbr. Forsk. 6 : 393-418. 1939.
10. Nowosad, F. S. Preliminary tests with some plant hormones in the rooting of cuttings of certain forage plants. Sci. Agr. 19 : 494-503. 1939.
11. Scholz, J., and B. Smidrkal. Propagation of cuttings of herbage plants by means of growth-promoting substances. Herb. Reviews 7 : 176-180. 1939.
12. Stoutemyer, V. T. Talc as a carrier of substances inducing root formation in softwood cuttings. Amer. Soc. Hort. Sci. Proc. 36 : 817-822. 1938.
13. Torssell, R. Influence of external factors on seed setting in lucerne. Ann. Royal Agr. College of Sweden, 3 : 191-241. 1936.
14. Tysdal, H. M., and J. R. Garl. A new method for alfalfa emasculation. J. Am. Soc. Agron. 32 : 405-407. 1940.
15. White, W. J. An improved method of rooting alfalfa cuttings. Sci. Agr. 26 : 194-197. 1946.

REACTION OF SMALL GRAINS TO VARIOUS DENSITIES OF WILD MUSTARD AND THE RESULTS OBTAINED AFTER THEIR REMOVAL WITH 2,4-D OR BY HAND

I. EXPERIMENTS WITH WHEAT[1]

V. D. Burrows and P. J. Olson[2]

The University of Manitoba, Winnipeg, Man.

[Received for publication August 23, 1954]

ABSTRACT

Spring wheat (*Triticum aestivum* L.), sown at the rate of 2 bushels per acre in 1952, and at 1, 2, and 3 bushels per acre in 1953, was grown alone or in association with various densities of wild mustard (*Brassica arvensis* (L.) Rabenh.). When the wheat was in the 5-leaf stage in 1952, and the early 4-leaf stage in 1953, some of the plots were sprayed with 2,4-D butyl ester at the rate of 6 ounces and 4 ounces acid equivalent per acre, respectively.

The experimental results obtained revealed that the presence of wild mustard affected adversely the growth, tillering and yield of wheat. Tillering and yield were reduced in both the sprayed and the unsprayed plots in 1952, but only in the unsprayed plots in 1953, believed to be due to the removal of the weed at an earlier stage of growth in the latter year. In general, while increasing the seeding rate of wheat increased the yield of grain in weedy plots, this was not the case where weeds were removed with 2,4-D or by hand.

INTRODUCTION

A considerable amount of recent research on weeds has dealt with the direct influence of weeds on the growth of plants, and with the effect of herbicides when applied to weeds and crops growing separately or together. It was found (1, 2, 4, 5, 7, 8) that competition from weeds may lower the yield of crop; and that the species of weed (8), as well as its abundance in the crop (2), influences the magnitude of the reduction. Weeds and crops compete principally for moisture, light and nutrients (7), and, if the weeds are aggressive, such competition usually reduces vigour, tillering, size of head, kernel weight, and yield in cereal crops (1, 2, 4, 5).

To increase the competitive efficiency of cereal crops Godel (4) and Pavlychenko (7), advocated the use of fertilizers and heavier than normal rates of seeding. However, since the advent of systemic herbicides (2,4-D and related compounds) farmers have had at their disposal an effective means of controlling many of the weed species occurring in grain fields. The main drawbacks are, first, that cereals can be treated satisfactorily only during certain stages of growth (3, 6) and, second, that the benefit gained from controlling small infestations of weeds may not justify the expense of treatment.

The main objectives of the present investigation were to determine (*a*) the reaction of wheat, sown at 1, 2, and 3 bushels per acre, to various densities of wild mustard, and (*b*) the effect on wheat of chemical control of the weed when its density was at different levels. It was hoped that these studies would show the lowest level of weed density in fields of wheat at which the spraying of wild mustard with 2,4-D would be justified financially for the current crop, and whether the seeding rate of wheat should be increased on weedy land when treatment of the crop with 2,4-D is contemplated.

[1] Contribution from the Division of Plant Science, The University of Manitoba, Winnipeg, Manitoba.
[2] Research Assistant and Professor, respectively, Division of Plant Science, The University of Manitoba.

MATERIALS AND METHODS

This study was conducted at the University of Manitoba in the years 1952 and 1953. Wheat was selected because of its economic importance and its tolerance, at certain stages of growth, to 2,4-D. The weed (wild mustard) used in these experiments was chosen because of its prevalence in Canada and its pronounced susceptibility to 2,4-D.

In 1952, the experiment consisted of quadruplicate blocks, and each block contained seven randomized main plots with different densities (0, 10, 25, 50, 100, 200 and 400 plants per square yard) of wild mustard. The density of wheat plants (variety Lee sown at 2 bushels per acre) was uniform for all plots. Each main plot was divided into two subplots, one of which was sprayed with 2,4-D and the other left unsprayed.

In 1953, the experiment consisted of quadruplicated blocks, but each block contained five main plots with a different density (0, 50, 100, 200 and 400 plants per square yard) of wild mustard. Each main plot contained nine randomized subplots, consisting of three treatments (unsprayed, sprayed, and hand-weeded) at each of three levels of seeding (1, 2, and 3 bushels of Lee wheat per acre).

In both experiments, the wild mustard seed was sown first, a predetermined amount being broadcast by hand over each plot and covered with soil by means of a garden rake. The wheat was sown afterwards, in rows 6 inches apart. In 1952, the sowing was done with a horse-drawn single disk drill, and in 1953, with a "Planet Junior" seeder. After seeding, the soil was packed to encourage uniform germination. In each year the process of sowing the plots was completed within one day.

Upon emergence, the mustard seedlings were counted and thinned to the density planned for each plot. Other weeds were removed as soon as they were detected.

In both years, the chemical applied was 2,4-D butyl ester. The plots were sprayed at the rate of 6 ounces acid equivalent per acre in 1952, and at the rate of 4 ounces per acre in 1953. At the time of spraying in 1952, the wheat was in the 5-leaf stage of growth (12-14 inches stretched height), and the mustard was 9 to 10 inches in height. In 1953, the spraying was done when the wheat was in the early 4-leaf stage (9-10 inches stretched height), and the mustard was 2 to 5 inches in height. In each year, the hand-weeding and spraying was done on the same day.

When the wheat was ripe, the plots were trimmed to provide against any 'border' effect. In 1952, the trimmed plots were 16.5 feet in length, and six drill rows in width, while, in 1953, they were 10 feet in length, and four drill rows in width. The number of culms per plot, the total dry weight of wheat plants, and the dry weight of mustard (unsprayed plots) was determined after harvest. The weight of straw (sheaf weight minus grain weight), the yield of grain, the bushel and 1000-kernel weights, the commercial grade, and the protein content of the seed were determined after threshing.

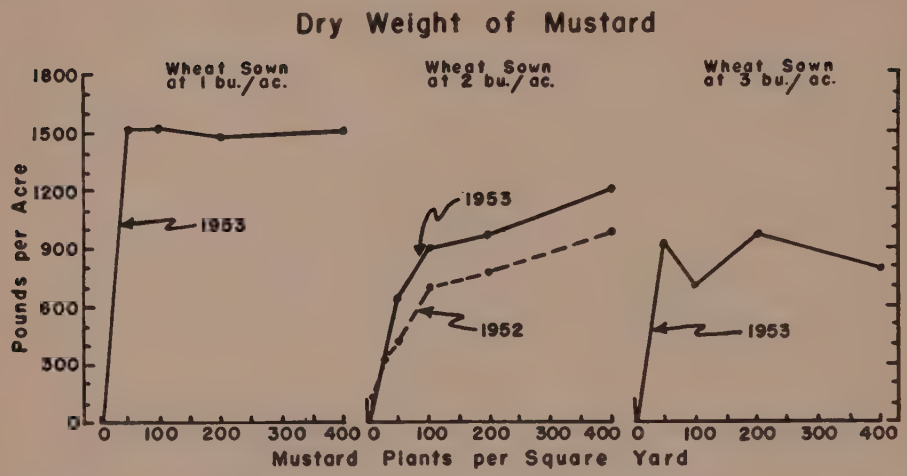

FIGURE 1. Dry weight of wild mustard (pounds per acre), at various levels of density in unsprayed plots of wheat sown at the rate of 1, 2, and 3 bushels per acre.

EXPERIMENTAL RESULTS

Dry Weight of Wild Mustard

The average total dry weight of wild mustard per plot was found to decrease as the rate of seeding wheat increased, probably as a result of greater competition from the wheat. Where wheat was sown at 1 bushel per acre, the total dry weight of mustard plants was not related to their density (Figure 1). At 2 bushels per acre, the total dry weight of mustard plants increased as their density increased, while at the 3-bushel rate, their total dry weight fluctuated, with no consistent upward or downward trend.

Wheat Culms per Square Yard

Tillering of wheat was measured by counting the number of culms per plot, and the results obtained are illustrated in Figure 2. In 1952, the average number of culms per square yard, in both the sprayed and the unsprayed plots, decreased as the density of mustard plants increased, and the differences between levels of density were statistically significant. The spraying of the plots with 2,4-D, 20 days after the mustard plants emerged, did not change this trend.

In 1953, the number of culms per square yard was also reduced significantly by wild mustard in the unsprayed plots, at all three seeding rates, but the lowest reduction took place at the 3-bushel rate. Again, the average number of culms per square yard decreased progressively as the density of mustard plants increased. However, at each level of mustard density, the average number of culms per square yard increased progressively as the rate of sowing increased. The removal of wild mustard, either by hand or by spraying with 2,4-D, 18 days after emergence, gave culm counts, at all three seeding rates, approximately equal to those of plots initially weed-free. It is interesting to note that, in the weed-free plots, wheat sown at 1 bushel per acre did not produce as many culms per square yard as it did when sown at 2 or 3 bushels per acre.

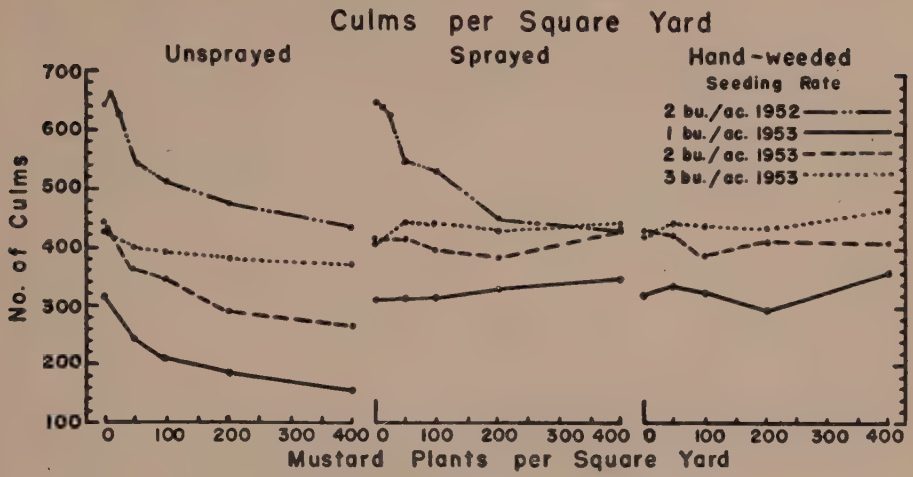

FIGURE 2. Number of culms per square yard in unsprayed, sprayed, and hand-weeded plots of wheat sown at the rate of 1, 2, and 3 bushels per acre and grown in association with various densities of wild mustard.

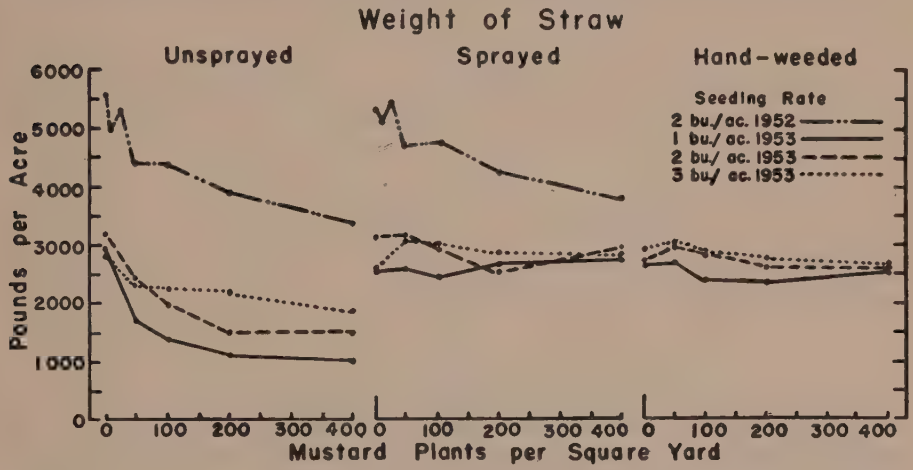

FIGURE 3. Weight of straw (pounds per acre) in unsprayed, sprayed and hand-weeded plots sown at the rate of 1, 2, and 3 bushels per acre and grown in association with various densities of wild mustard.

Yield of Straw

The average yields of straw are shown in Figure 3. A comparison of Figure 2 and Figure 3 reveals that the trends for the number of culms per square yard and those for straw yield are very much alike. This indicates a direct relationship between the total number of culms per square yard and the yield of straw.

Yield of Grain

As shown in Figure 4, the yield of grain tended to decrease as the density of wild mustard increased in both the sprayed and unsprayed plots in 1952. The downward trend was most pronounced at the lower densities. Spraying the plots with 2,4-D to destroy weeds did not increase the yield significantly at any level of weed density.

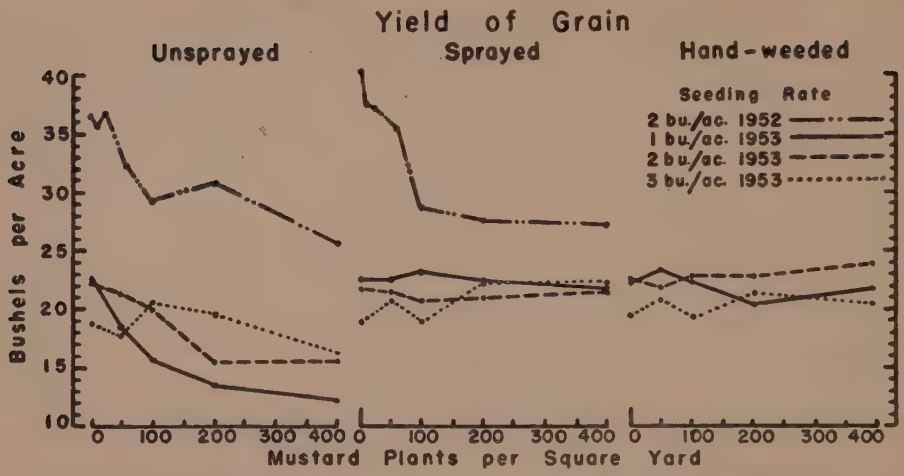

FIGURE 4. Yield of grain (bushels per acre) in unsprayed, sprayed, and hand-weeded plots sown at the rate of 1, 2, and 3 bushels per acre and grown in association with various densities of wild mustard.

In 1953, competition from wild mustard in the unsprayed plots reduced significantly the yield of grain at all three rates of seeding. At rates of 1 and 2 bushels per acre, the yield from weed-free plots was about the same but, where weeds were present, the yield decreased progressively as the density of mustard increased. Where wheat was sown at 3 bushels per acre, the yield of grain from weed-free plots was lower than that of similar plots sown at the 1- and 2-bushel rates but was not as strongly depressed with increase in weed density and tended to fluctuate. Despite the fact that there was a general downward trend in yield with increase in mustard density, an increase in the rate of seeding on weedy land improved the yield.

The spraying and removal of weeds by hand resulted, in 1953, in a yield of grain comparable to the weed-free check plots.

It has already been shown (Figure 2) that the average number of culms per square yard of weed-free plots sown at 1 bushel per acre was much lower than that of similar plots sown at 2 and 3 bushels per acre. Despite this fact, the yields of grain from wheat sown at 1 bushel and 2 bushels per acre were approximately equal. It is suggested that the larger spikes which developed in the plots sown at 1 bushel per acre compensated for the fewer culms and equalized the yield.

Bushel and 1000-Kernel Weight

In both 1952 and 1953, the average bushel weight of wheat seed from weedy plots was significantly higher than that from the sprayed plots (Table 1). The difference between the averages for different levels of mustard density, however, were not significant.

The 1000-kernel weight was not affected significantly by either wild mustard or 2,4-D in 1952. In 1953, the 1000-kernel weight was affected by both the rate of seeding and the presence of weeds (Table 2). As the rate of seeding increased, the 1000-kernel weight decreased. This may be due to the inverse relationship usually found between head and kernel size

TABLE 1.—EFFECT OF WILD MUSTARD ON BUSHEL WEIGHT (LB.) OF WHEAT FROM PLOTS SOWN AT DIFFERENT RATES AND SUBJECTED TO DIFFERENT METHODS OF WEED CONTROL

Year	Seeding rate (bu./ac.)	Method of weed control			
		None	2,4-D spray	Hand-weeding	Mean (1953)
1952[1]	2	63.97	63.17	—	—
1953[2]	1	62.76	60.69	59.60	61.02
	2	62.10	60.18	60.34	60.88
	3	60.92	60.38	59.78	60.36
Mean (1953)	—	61.93	60.42	59.91	—

[1] Significant difference (5 per cent point) between means for methods was 0.68 lb.
[2] Significant difference (5 per cent point) between means for methods was 0.50 lb., of means for rates 0.50 lb., and of interaction (methods × rates) 1.13 lb.

TABLE 2.—EFFECT OF WILD MUSTARD ON 1000-KERNEL WEIGHT (GRAMS) OF WHEAT PLOTS SOWN AT DIFFERENT RATES AND SUBJECTED TO DIFFERENT METHODS OF WEED CONTROL

Seeding rate (bu./ac.)	Method of weed control			
	None	2,4-D spray	Hand-weeding	Mean[1]
1	33.28	33.18	30.54	32.00
2	30.62	29.39	29.12	29.71
3	28.58	28.55	28.04	28.39
Mean[2]	30.83	30.04	29.23	—

[1] Significant difference (5 per cent point) between means for rates 0.65 grams.
[2] Significant difference (5 per cent point) between means for methods 0.65 grams.

and the density of stand. The kernels in threshed grain from weedy plots were also more uniform in size than those taken from sprayed or hand-weeded plots.

Commercial Grade and Protein Content of the Grain

The commercial grade of wheat was not affected by either the degree of weediness in the different kinds of plots or the method of weed control, but the protein content was significantly lower in plots where wild mustard was present (Table 3). There was no differential response, with respect to protein content, to either the rate of seeding or weed density.

DISCUSSION AND CONCLUSIONS

The results obtained during this investigation confirm those of earlier workers as regards the serious effects of aggressive weeds upon growth, tillering and yield.

TABLE 3.—EFFECT OF WILD MUSTARD ON PROTEIN CONTENT (PER CENT) OF WHEAT SOWN AT DIFFERENT RATES AND SUBJECTED TO DIFFERENT METHODS OF WEED CONTROL

Year	Seeding rate (bu./ac.)	None	Method of control		Mean
			2,4-D spray	Hand-weeding	
1952[1]	2	12.41	13.07	—	—
1953[2]	1	14.13	14.59	14.95	14.56
	2	14.10	14.87	14.62	14.53
	3	14.31	14.71	14.78	14.60
Mean (1953)	—	14.18	14.72	14.79	—

[1] Significant difference (5 per cent point) between means for methods was 0.58 per cent.
[2] Significant difference (5 per cent point) between means for methods was 0.31 per cent; differences between means for rates were not significant.

The selection of a method of reducing the hazard from weeds often causes concern. Efforts to reduce it by special cultural practices have often been uneconomical, and more often unsuccessful. The horizon-wide yellow expanses of wild mustard in bloom so characteristic of the Great Plains area a few years ago is ample proof of the latter. The introduction and use of systemic herbicides has greatly reduced the hazard caused by many weeds but these 'miracle' chemicals have their limitations. Some of these limitations are well known, and others seem to require investigation.

The experimental evidence obtained during this investigation suggests the necessity for spraying wild-mustard infested wheat fields when the weed is in an early stage of growth. In 1952, it was found that wild mustard reduced tillering to an equal extent in both sprayed and unsprayed plots. Evidently it affected the growth of wheat before the latter had reached the 5-leaf stage of growth, since this was the stage at which the mustard was destroyed with 2,4-D. Also, the effect on wheat increased progressively with increasing density of the weed on both the unsprayed and sprayed plots. This reduction in tillering was followed by a reduction in total yield of straw and grain. In 1953, the plots of wheat were sprayed when the wheat plants were at the early 4-leaf stage and the results indicated that the mustard was killed before it had time to affect tillering, and in turn the yield of straw and grain. At all rates of seeding those yields were significantly higher in the sprayed than in the unsprayed plots.

The adverse effect of wild mustard on tillering of wheat was probably due in some measure to the competition between the two species for soil moisture. For the entire growing season of 1952 the amount of precipitation (10.06 inches) was much lower than in 1953 (15.38 inches). During the early part of the growing season, from seeding until the time of spraying, 4.77 inches of total precipitation were received in 1952, and 4.85 inches in 1953. While these figures are quite similar, it must be pointed out that the precipitation came at more or less regularly spaced intervals in 1953, but not in 1952. Of the 4.77 inches in 1952, 2.80 inches fell only four days before the date of spraying. Therefore, for most of the interval between seeding and spraying, less soil moisture was available in 1952 than in 1953.

If it is possible to destroy weeds soon after their emergence by harrowing or spraying with 2,4-D, heavy rates of seeding wheat should be avoided. In general, hand-weeded and sprayed plots of wheat sown at the rate of three bushels per acre produced less yield of grain than comparable plots sown at 1 and 2 bushels per acre (Figure 4).

Where a farmer is not equipped to spray for the control of weeds, evidence is presented to demonstrate the value of increased rates of seeding (Figure 4).

It is not possible to state, as a direct conclusion from this investigation, the level of density of wild mustard at which spraying with 2,4-D is worth while, in terms of a significant increase in yield of the current crop. In 1952, control of wild mustard by spraying did not result in an increase in yield, at any level of mustard density. However, in 1953, some significant increases in yield were obtained by spraying but the minimum weed density at which spraying could be considered justifiable depended on the seeding rate of wheat. At the 1-bushel rate, the critical weed density was 50 plants per square yard (the lowest level of weed density used) but for the 2- and the 3-bushel rates it was 200 and 400 plants, respectively.

ACKNOWLEDGEMENTS

Grateful acknowledgement is extended to: Canadian Industries Limited for providing the financial assistance which made this study possible; and to J. A. Anderson, Chief Chemist, Grain Research Laboratory, Board of Grain Commissioners, for making the chemical determinations reported in this paper.

REFERENCES

1. Blackman, G. E., and W. G. Templeman. The nature of the competition between cereal crops and annual weeds. J. Agr. Sci. 28 : 247-271. 1938.
2. Carter, A. S., J. H. Lefforge, and L. C. Shenberger. A study of the effect of infestations of field peppergrass (*Lepidium campestre*) on the yield of wheat. Proc. Assoc. Off. Seed Analysts 36 : 103-105. 1946.
3. Friesen, G., and P. J. Olson. The effect of 2,4-D on the developmental processes in barley and oats. Can. J. Agr. Sci. 33 : 315-329. 1953.
4. Godel, G. L. Relation between rate of seeding and yield of cereal crops in competition with weeds. Sci. Agr. 16 : 165-168. 1935.
5. Godel, G. L. Cereal growing on weedy land in northern Saskatchewan. Sci. Agr. 19 : 21-32. 1938.
6. Olson, P. J., S. Zalik, W. J. Breakey, and D. A. Brown. Sensitivity of wheat and barley at different stages of growth to treatment with 2,4-D. Agron. J. 43 : 77-83. 1951.
7. Pavlychenko, T. K. Plant competition and weed control. Agr. Inst. Rev. 4(2) : 142-145. 1949.
8. Pavlychenko, T. K., and J. B. Harrington. Competitive efficiency of weeds and cereal crops. Can. J. Res. 10 : 77-94. 1934.

DISTRIBUTION OF VEGETATIVE BUDS ON THE UNDERGROUND PARTS OF LEAFY SPURGE (*EUPHORBIA ESULA* L.)[1]

ROBERT T. COUPLAND AND JACK F. ALEX[2]

Department of Plant Ecology, University of Saskatchewan, Saskatoon, Sask.

[Received for publication August 19, 1954]

ABSTRACT

Data are presented concerning the distribution of reproductive buds on the underground parts of leafy spurge, a persistent perennial weed which is becoming abundant in Saskatchewan. The presence of these buds is considered to be a major cause of the persistence of the species even when vigorous attempts are made to control it. The buds were counted at various levels on 65 roots from 13 excavations. The maximum depth to which they were found varied from 12 inches to 68 inches. The roots examined were divided into three groups, on the basis of number of buds occurring per root (means were 72, 272 and 35). The data suggest that 97 per cent of the variability in the mean number of buds per root among different 6-inch layers is associated with a similar variability in the weight of root material. Sixty-two per cent of the buds were found in the A horizon of soil. The possible effects of other factors on bud distribution are considered. These data are discussed in relation to control practices.

INTRODUCTION

In a previous paper (2) the distribution of the underground plant parts of leafy spurge (*Euphorbia esula* L.) has been discussed as determined from excavation of root systems of this persistent perennial weed from 22 sites in various parts of Saskatchewan. In the present paper data are presented concerning the distribution of reproductive buds on the underground parts of this species (Figure 1). The authors are of the opinion that the presence of these buds to a considerable depth in the soil is related to the persistent characteristics of this species.

The occurrence of vegetative buds on the underground parts of leafy spurge has been discussed briefly by other authors. Harrington *et al.*[3] reported that pinkish vegetative buds were found on roots of 5-year-old plants to a maximum depth of 17 inches below the soil surface. Hanson and Rudd (3) described the very frequent occurrence of pinkish buds on underground stems above the zone of transition to root as well as on the roots below this region. They found that buds were numerous in the first foot of soil but were smaller and less abundant at greater depths. Forty-two inches was the maximum depth at which buds were observed. These investigators also reported that these buds produced shoots very readily, especially if the upper part of the stem had been injured or killed by tillage or herbicide. Bakke (1) reported that buds occur when conditions are favourable. In one instance, he found them on roots at a depth of 7 feet below the soil surface. In another excavation, shoots developed at a depth of 10 feet below the soil surface and grew out into the excavated area.

[1] This paper is based partly on a thesis presented by the junior author to the College of Graduate Studies of the University of Saskatchewan in partial fulfilment of the requirements for the degree of Master of Science in Plant Ecology. The study was financed by grants from the Saskatchewan Agricultural Research Foundation.

[2] Associate Professor and formerly Graduate Assistant in Plant Ecology, respectively.

[3] Harrington, J. B., T. K. Pavlychenko, W. Kossar and O. M. Anderson. Report of investigations carried on in 1937 at the Weed Research Laboratory, University of Saskatchewan. 1938.

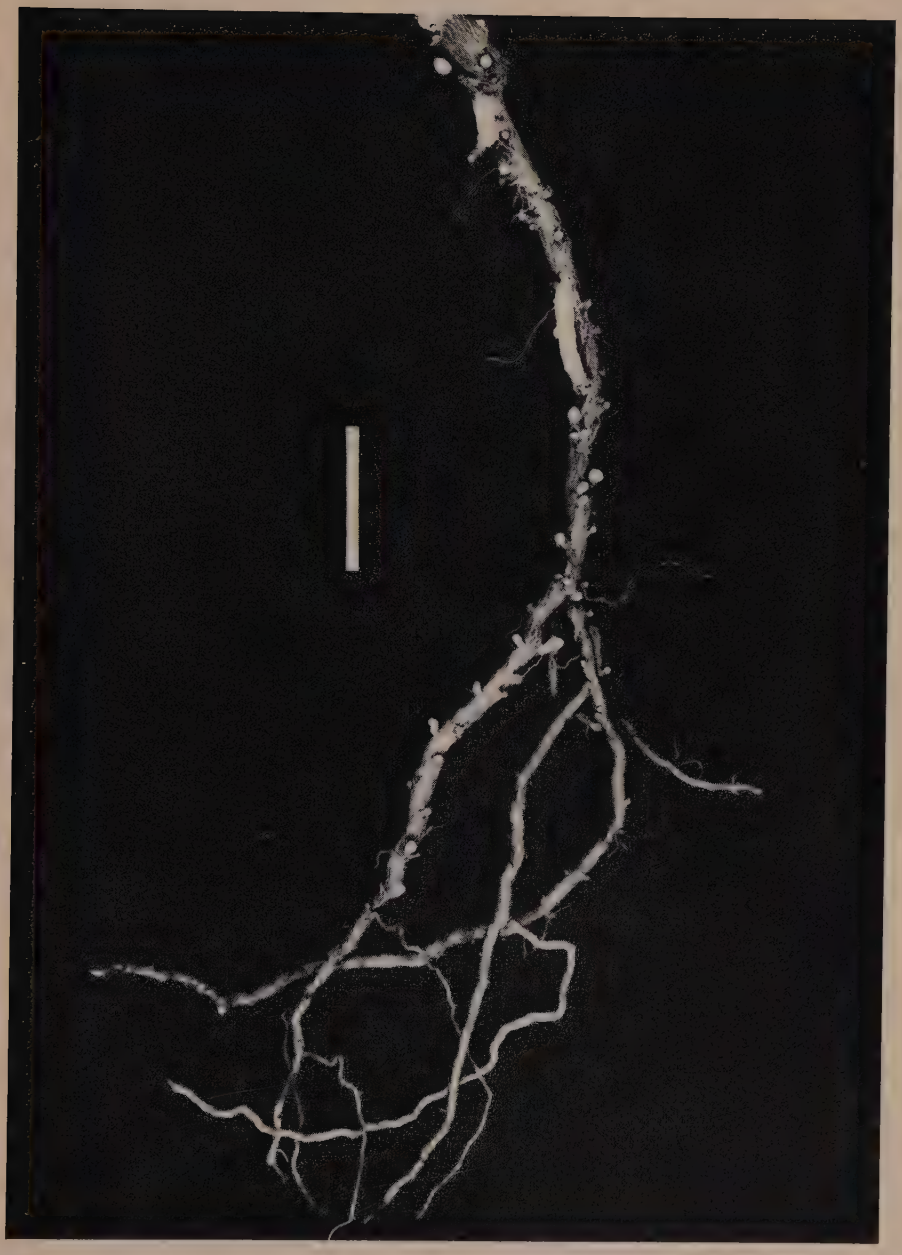

FIGURE 1. Underground structure (stem-root transition) of leafy spurge to a depth of 8 in., showing the presence of numerous reproductive buds (whitish nobs). One of these has enlarged preparatory to producing a stem shoot. The white line on the left is one inch in length.

The purpose of the present investigation was to obtain more detailed data concerning the abundance of vegetative buds on underground parts of stands of leafy spurge in Saskatchewan and to discover what factors affect their development.

METHODS AND PROCEDURE

The occurrence of buds was examined on 65 roots* of leafy spurge which were obtained by using the tracing method (7) in 13 excavations during 1950. The soils excavated ranged in texture from sand to clay loam and were located in both the dark-brown and black soil zones (4). The soil around the root on the vertical face of the excavation was probed with an ice-pick until the loosened soil fell away and exposed the root. Most of the very small root branches were lost by this method because they adhered to the soil particles and were broken off. The roots so exposed were tagged at each 12-inch interval from the surface, were numbered for future identification, and were either wrapped in damp cloth or placed in water.

Each root was examined in detail in the laboratory for occurrence of buds usually within two days after removal from the soil. The number of buds occurring on the root in each 1-inch layer of soil was counted. Although vegetative buds occur on both vertical and horizontal roots, only those produced on vertical roots were counted in this study. Arbitrarily, a root was classified as vertical if the portion occurring within a 1-inch layer of soil was not longer than 2 inches.

Three classes of vegetative buds were recognized—active, inactive and dead. Those buds which were pink to white in colour and appeared to be in a growing condition were termed "active". "Inactive" buds were yellow to light-brown in colour and were apparently composed of living tissue which was more or less dormant from the viewpoint of development. "Dead" buds were those in which the tissue was apparently dead or lignified. The numbers of all three classes were counted at the beginning of the study. Later the dead buds were not counted because of their erratic occurrence. Unless otherwise stated, the terms "buds", "vegetative buds" and "reproductive buds" in this paper refer to the sum of the active and inactive buds.

EXPERIMENTAL RESULTS

Distribution of Buds According to Depth

The number of vegetative buds per unit length of root (or rhizome) tended to be greatest just below the soil surface and to decrease with increasing depth. The maximum depth to which they were found varied greatly from 12 inches in one excavation to 68 inches in another. In one excavation the maximum depth of buds recorded on six roots ranged from 25 to 59 inches, while in another it varied only from 66 to 68 inches on four roots.

The average number of buds was calculated for each 1-inch layer on all the roots examined from each excavation. Plotting, for each of the 13 excavations, the curve representing the average number of buds per

* The term "root" is used here to include vertical rhizomes and the root-stem transition region of each underground structure.

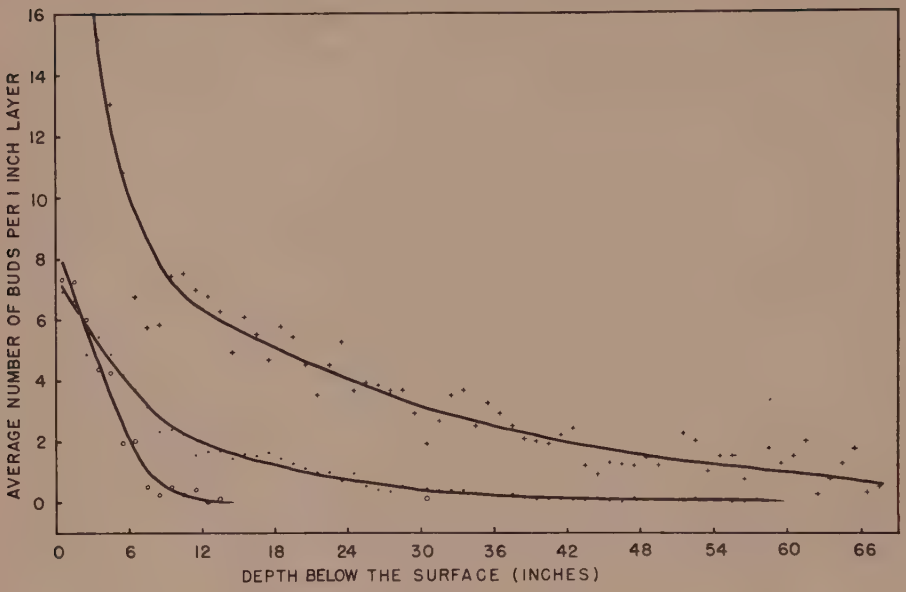

FIGURE 2. Weighted average distribution of vegetative buds on the underground parts of leafy spurge in three groups of excavations. Each plotted point represents the weighted average number of buds per 1-inch layer per excavation in each group.

1-inch layer against the depth in inches, indicated the occurrence of three general types of distribution of buds. For each group of excavations the average distribution of buds per excavation was calculated by dividing the sum of the average number of buds in each 1-inch layer of all excavations by the number of excavations in which data for that depth were available. The three resulting curves are plotted in Figure 2.

The middle curve in the graph represents the average distribution of buds in eight excavations in which a total of 48 roots were examined. The average number of buds decreased from 6.92 in the surface 1-inch layer to 1.56 in the 11- to 12-inch layer and was less than one per root in each 1-inch layer of soil below 21 inches. On most roots in this group the buds occurred only to a depth of 30 to 38 inches, although in two excavations they were found below 50 inches.

In one group of three excavations the average number of buds per root was generally greater than in the first group. This difference was especially consistent at depths greater than 12 inches. The average distribution in this group is represented by the uppermost curve in Figure 2. Buds occurred on nearly all roots of this group to a depth of 44 inches and were observed as deeply as 68 inches in one excavation.

In two excavations, in which a total of seven roots were examined, a very rapid decline occurred in the number of buds found at increasing depths (lower curve in Figure 2). In one of these the average number of buds per root decreased from 12 in the surface 1-inch layer to the extent that only one bud was found below 7 inches. In the second excavation no buds were found below a depth of 14 inches except for one at 30 inches below the soil surface.

The mean total numbers of buds per root per excavation in the above groups were 72, 272, and 35, respectively. The ranges (49 to 98, 196 to 280, and 27 to 44) indicate that significant differences may occur between these groups in total numbers of buds per root. Calculations showed, however, that the differences in numbers of buds per 1-inch layer on each root of each group were not significant because of the variability which was encountered. This variability was relatively small within any one excavation, was greater among means from different excavations, and greatest among numbers of buds on individual roots in different excavations. This indicates that differences in habitat and possibly genetic stock were probably responsible for the wide variation encountered.

Distribution of Buds in Relation to Weight of Underground Parts

From 11 of the 13 excavations, in which distribution of buds was studied on the roots of leafy spurge, data were also available concerning the distribution of the underground parts of this species by weight to a depth of 48 inches (2). The degree of relationship between these two attributes was studied to ascertain the extent to which the distribution of vegetative buds was affected by the weight of root material present. This relationship was measured by means of the correlation coefficient and the coefficient of determination as defined by Pearson and Bennett (5).

The mean number of buds per root in each 6-inch layer from the surface to 48 inches was compared with the weight of underground parts of leafy spurge found in 216 cubic inches of the corresponding layer in the same excavation. Comparisons were made only in layers where buds were present. The number of excavations represented in the data therefore decreased from 11 in the surface layers to 4 in the 42- to 48-inch layer.

TABLE 1.—DEGREE OF ASSOCIATION BETWEEN THE NUMBER OF BUDS AND WEIGHT OF UNDERGROUND PLANT MATERIAL OF LEAFY SPURGE IN SUCCESSIVE 6-IN. LAYERS OF SOIL TO A DEPTH OF 48 IN.

Soil layer (in.)	No. of excavations compared (both roots and buds present)	Weighted means		Coefficient of determination (r^2)
		Weight of underground plant parts (gm.)	No. of buds per root	
0– 6	11	9.00	44.40	0.0003
6–12	11	3.71	16.22	0.437
12–18	10	1.68	12.70	0.413
18–24	9	1.21	11.61	0.059
24–30	9	0.83	6.80	0.019
30–36	7	0.47	7.44	—
36–42	6	0.55	5.45	—
42–48	4	0.37	4.38	—

The coefficient of determination (r^2) calculated from these data was 0.970. This suggests that 97 per cent of the variability in the mean number of buds per root among different 6-inch layers is associated with a similar variability in the weight of root material. However, this does not necessarily mean that one is dependent upon the other.

The data available failed to show association between weight of underground parts and number of buds in individual layers except in the 6- to 12-inch and 12- to 18-inch layers (Table 1). Since these calculations have eliminated depth as a variable, the assumption may be made that the number of buds occurring in the latter layers of soil are to some extent associated with, or possibly dependent upon, the weight of root material in each layer. Confirmation of this assumption would require further investigation with a larger number of samples.

Distribution of Buds in Relation to Soil Characteristics

The effects of certain soil characteristics* were investigated as possible causes of the differences apparent in the distribution of buds on underground parts of leafy spurge in different habitats.

Some difficulty was experienced in studying the distribution of buds in the various soil horizons because of the variation in depth of soil horizon and absence of horizons in some profiles. Therefore, data were grouped only for the major horizons (A, B and C or D). Where an A-B transition occurred, this was combined with the A horizon. The total numbers of buds per root were more variable in the A horizon (25 to 184) than in the others. On the average (of 13 excavations) 62 per cent of the buds occurred in the A horizon.

It is interesting to note that in those excavations represented by the uppermost curve in Figure 2, 63 per cent of the buds occurred in the A horizon, while this value for the middle curve was 60, and for the lower curve 90 per cent. The respective proportions of the number of buds occurring in the B horizon were 20, 32 and 8 per cent.

The influence of texture of the surface horizons on the abundance of bud development was investigated. The following arrangement of textures represents the order of decreasing abundance of buds (mean numbers per 1-inch layer in parentheses): very fine sandy loam (11.0), silty clay loam (6.9), silty loam (5.0), fine sandy loam (4.0), and loamy sand (3.1). The high variability in occurrence of buds in deeper layers prevented a similar trend in differences to be shown among textures of soils of lower horizons.

A preliminary investigation indicated the absence of any relation between the abundance of buds and soil consistence (hardness) in any one layer or in the profile as a whole.

The distribution of buds was examined in relation to the amount of calcium carbonate in the soil. In two excavations, 44 per cent of the buds occurred in the region above the zone of accumulation of calcium carbonate. In all other excavations, 58 per cent or more of the buds were found in the region above the lime. No relationship was found between the amount of lime present and the number of buds occurring at any level in the soil.

* Personnel of the Saskatchewan Soil Survey described the soil profile in each of the excavations.

Other Factors Affecting Distribution of Buds

Early in the study observations indicated that the use to which land was being put might have a pronounced effect on the distribution of buds on the underground parts of leafy spurge. Unfortunately, the small number of samples taken under different land uses on the same soil type prevented speculation on this point. The possibility of a genetic factor being involved should also be investigated. However, this would involve the introduction of the species to one habitat from several different habitats. Past experience has shown the authors that attempted introductions are not always successful in producing stands sufficiently vigorous for comparison.

DISCUSSION

The distribution of buds on underground parts of leafy spurge is important in relation to control practices. Although the data were insufficient to show any effect of cultivation on distribution of buds, this method of control probably does affect the number of buds found at different depths in the soil. In a later paper data will be presented to show the effect of severance of the roots in stimulating development of buds into leafy shoots. The authors are of the opinion that the difficulty in eradication of this weed by black summerfallow which has been reported is partially a consequence of the high reproductive capacity of vegetative buds on the roots remaining below the tilled layer.

The success of a herbicide in eradicating patches of this weed may be determined in part by the distribution of buds at various depths in the soil. To be effective the herbicide must affect all buds down to that depth in the soil below which they cannot develop into new shoots capable of reaching the soil surface. That this depth is at least 3 feet has been demonstrated by the present authors.* Plant physiologists have found that hormone-like herbicides, such as 2,4-D, are not translocated from the leaves of leafy spurge to a depth in the underground parts below the crown (6). It is therefore difficult to see how these herbicides could be expected to be effective in the eradication of leafy spurge unless applications capable of destroying the plant to the crown level were repeated at sufficiently frequent intervals to keep the surface free of leafy growth. This procedure could not be expected to be more effective than thorough cultivation. Likewise, the success of eradication by soil sterilization will depend on the characteristics of the herbicide used. A chemical which is highly water soluble will be more effective in reaching the deeper buds, but the depth of penetration will depend on the rainfall. Under the arid conditions in which some stands of leafy spurge thrive, it is improbable that penetration will be sufficiently deep to destroy buds to the level from which reproduction is possible. This is particularly true in soils of fine texture. If the sterilant does reach a sufficient depth, the concentration may be so lowered that it is no longer toxic. It is probable that soluble herbicides capable of destroying plant tissue to sufficient depths will leave the surface layers of soil with concentrations too low to prevent shoot development to the surface from root tissue which escapes destruction. Germination of seeds will then also

* Data to be presented in a later paper.

be possible and may indeed be stimulated, judging from the dense stands of seedlings which the authors have found in areas treated with compounds containing sodium chlorate.

A relatively insoluble herbicide which is capable of sterilizing the soil surface for long periods may be most effective in eradication of patches of this weed. Such treatment would prevent any shoot development to the surface in thoroughly treated areas. However, this treatment would presumably not destroy the root system below the surface layer. This reproductive tissue would remain in a position to produce shoots through parts of the treated area where the concentration of the herbicide is or falls below toxic levels (treatment is rarely sufficiently uniform to prevent this from happening). Also, shoots may arise from this underground reserve in the periphery of the patch, unless extreme care is taken in applying the herbicide in the zone surrounding the patch. The removal of this threat is only possible by the use of a soluble herbicide. The conclusion is, therefore, reached that more success in eradication may be possible through the use of a mixture of two herbicides, one soluble and one relatively insoluble. The use of a relatively insoluble compound is obviously disadvantageous from the standpoint of the prolonged effect on the productivity of the soil following eradication of the weed.

ACKNOWLEDGEMENTS

The field work was assisted by T. C. Brayshaw and W. Budz. H. C. Moss and other members of the Soil Survey staff of the Department of Soil Science, University of Saskatchewan, described the soil profiles.

REFERENCES

1. Bakke, A. L. Leafy spurge, *Euphorbia esula* L. Iowa Agr. Expt. Sta. Bull. 198. 1936.
2. Coupland, R. T., and J. F. Alex. Distribution of the underground parts of leafy spurge (*Euphorbia esula* L.). Can. J. Agr. Sci. 34 : 161-176. 1954.
3. Hanson, H. C., and V. E. Rudd. Leafy spurge—life history and habits. N.D. Agr. Expt. Sta. Bull. 266. 1933.
4. Mitchell, J., H. C. Moss, and J. S. Clayton. Soil survey of southern Saskatchewan from Township 1 to 48, inclusive. Soil Survey Report No. 12, Univ. of Sask. 1944.
5. Pearson, F. A., and K. R. Bennett. Statistical methods, p. 154. John Wiley and Sons, New York. 1942.
6. Switzer, C. M., and R. O. Bibbey. Translocation of herbicides in leafy spurge. Proceedings of the 9th North Central Weed Control Conference, p. 32. 1952.
7. Weaver, J. E. Root development of field crops. McGraw-Hill Book Co., Inc., New York. 1926.

THE USE OF DESICCANTS FOR THE PRE-HARVEST TREATMENT OF LEGUME SEED CROPS[1]

R. M. MacVicar and D. R. Gibson[2]

Central Experimental Farm, Ottawa, Canada

[Received for publication September 21, 1954]

ABSTRACT

Small plot trials and field trials were conducted over a 3-year period to evaluate the practice of crop desiccation in legume seed harvesting. Sodium cyanamide, potassium cyanate, dinitro (dinitro-o-secbutylphenol) pentachlorophenol and endothal (disodium 3-6-endoxohexahydrophthalate) were used alone and in combination with diesel and aromatic oil on crops of alsike, ladino, birdsfoot trefoil, red clover and alfalfa.

An appreciable reduction in moisture content was brought about by the desiccant treatments. However, seed yields were not increased while in some cases there was evidence of extensive shattering due to the application of the desiccants. Alsike became completely decumbent after treatment and thus very difficult to harvest.

The data obtained did not indicate that the pre-harvest spraying of legume seed crops would be a profitable practice in areas such as eastern Ontario where seed yields are generally low.

INTRODUCTION

The pre-harvest curing or desiccation of legume seed crops prior to threshing is a practice which has been adopted in certain legume seed producing areas in recent years. This procedure is reputed to facilitate harvest to the extent that direct combining can be practised as opposed to the method of conditioning the crop in the windrow prior to threshing. When legume seed crops are windrowed, seed loss from shattering can be very extensive. When conditions are such that direct combining can be practised, harvesting losses are reduced.

Recent work by Jones (5) indicated that in California the harvest of such crops as alfalfa, ladino, alsike and trefoil was facilitated under some circumstances with an aeroplane spray of 2 to 3 pints of dinitro in 10 to 15 gallons of diesel oil per acre. Jones found that with ground sprayers twice the amount of oil, plus sufficient water to make an emulsion for rates of application up to 60 gallons per acre, was necessary.

Medler (6), working in Wisconsin, found that a relatively new chemical, endothal, offered considerable promise as a drying agent on crops such as alfalfa, ladino, red clover, alsike and birdsfoot trefoil. Medler suggested that, while drying may not increase seed yields, the harvesting of legume seed could be speeded up and cleaner seed obtained.

Slife (7) in summarizing the use of desiccants in the north-central region of the United States, referred to tests made in Kansas and Nebraska which indicated that oil-based chemicals gave increased seed yields on crops such as alfalfa and sweet clover. The comparison here was between plots that were "direct combined" after desiccants were applied, and plots that were mowed for curing.

[1] Contribution from Division of Forage Crops, Central Experimental Farm, Ottawa.
[2] Agricultural Research Officer and Technical Officer, respectively.

Cooper and Corns (1), working in Alberta, studied the efficiency of various chemicals as drying agents. It was found that in pure stands of birdsfoot trefoil 25 to 30 lb. of sodium cyanamide per acre in 40 gallons of water resulted in a delay in pod dehiscence and permitted direct combining 5 days after treatment. Much the same results were obtained when alfalfa, alsike and red clover were treated with from 30 to 60 lb. of sodium cyanamide, or 15 to 35 lb. of potassium cyanate in 40 or more gallons of water.

Corns (2, 3, 4), also working in Alberta, concluded that aromatic oil and the dinitro-diesel oil mixtures produced the most satisfactory results. The treatments were effective in making the plant material suitable for direct combining, but such treatments did not always bring about increased seed yields. Under eastern Ontario conditions the herbage on the legume seed meadows frequently has a high moisture content at time of harvest. Because of this it was deemed worthwhile to test the efficacy of pre-harvest desiccants under the conditions that prevail here. The subject matter of this paper is derived from the results obtained.

MATERIALS AND METHODS

During 1951, 1952 and 1953, a number of small plot experiments and a few field trials were conducted at Ottawa with various crop desiccants. While it was not possible to conduct uniform tests during these years, it was possible by means of adequate replication to obtain data of some significance.

Small Plot Trials

Since little background information was available as a guide in setting up experiments, rates of application of the various materials used were more or less arbitrary. Treatments and rates of application in 1951 were as follows:

Treatment	*Rate per acre*
1. Control	No application
2. 2,4-D (amine)	1½ lb. acid equivalent in 20 gallons of water
3. Diesel oil	60 gallons
4. Mono-sodium cyanamid	60 lb. in 60 gallons of water (1 per cent Dreft as wetting agent)
5. Potassium cyanate	20 lb. in 60 gallons of water (1 per cent Dreft as wetting agent)
6. Esso 500	40 gallons
7. Dinitro plus diesel oil	3 pints in 15 gallons diesel oil
8. Pentachlorophenol	4 gallons.

In 1952 treatments 2, 4 and 8 were omitted and a further treatment of Esso 500 plus dinitro was added.

In 1951, treatments were applied to small plots of alsike and ladino by means of hand sprayers. In 1952, small plots of red clover, alsike, ladino and birdsfoot trefoil were treated in a similar fashion. Treatments were replicated four times in all cases. They were applied at a time when the crops were considered to be ready for harvest in so far as seed maturity was concerned. Records were taken 6 days later.

TABLE 1.—SEED YIELD, PER CENT DRY MATTER AND GERMINATION OF ALSIKE, LADINO, RED CLOVER AND BIRDSFOOT TREFOIL AS AFFECTED BY CROP DESICCANTS

Treatments	Alsike					Ladino				Red clover			Birdsfoot trefoil		
	1951		1952			1951		1952		1952			1952		
	Seed yield	Per cent germ.	Seed yield	Per cent germ.	Dry matter	Seed yield	Per cent germ.	Seed yield	Per cent germ.	Seed yield	Per cent germ.	Dry matter	Seed yield	Per cent germ.	Dry matter
	lb.		lb.		per cent	lb.		lb.		lb.		per cent	lb.		per cent
1. Control	28	87	14	82	33	46	69	31	92	86	90	56	11	54	26
2. 2-4-D (amine)	19	92	—	—	—	35	69	—	—	—	—	—	—	—	—
3. Diesel oil	25	81	10	80	29	30	89	—	93	103	88	56	6	46	26
4. Mono-sodium cyanamid	42	96	—	—	—	28	73	—	—	—	—	—	—	—	—
5. Potassium cyanate	34	96	8	73	41	24	60	38	96	84	91	61	4	46	32
6. Esso 500	32	89	10	74	35	49	72	30	93	110	93	58	4	55	28
7. Dinitro plus diesel oil	24	79	7	81	49	49	72	34	95	107	92	63	2	52	32
8. Pentachlorophenol	41	94	—	—	—	51	61	—	—	—	—	—	—	—	—
9. Esso 500 plus dinitro	—	—	8	78	44	—	—	30	96	102	92	66	2	48	32
L.S.D. (P. = .05)	—	—	—	5	8	—	—	—	—	—	—	6	—	5	3

In 1953 desiccants were applied to a crop of alfalfa. There were six replicates of each treatment. Observations were made at 4-, 8- and 11-day intervals after application. The treatments and rate of application were as follows:

Treatment	*Rate per acre*
1. Esso 500	20 gallons
2. Diesel oil	20 gallons
3. Endothal	2 gallons in 20 gallons of water
4. Dinitro plus diesel oil	3 pints in 20 gallons diesel oil
5. Esso Q × 5474B	20 gallons
6. Control	No application.

Field Trials

In addition to the small plot trials, small field trials were carried on in 1951 and 1952. In 1951 the same treatments as used in a small plot work were applied with a high pressure field sprayer to crops of red clover and alfalfa. Plots were approximately .180 acres in size and four replicates were used. Seed yields, combine loss in harvest, seed germination and dry matter determinations were obtained from the alfalfa experiment. Due to a sampling error, seed yield data of a useful nature were not obtained from the red clover plots. However, as with alfalfa, combine losses, germination and dry matter data were secured.

In 1952, an effort was made to assess the effectiveness of applying a desiccant to red clover in the windrow as opposed to applying it to the standing crop. The drying chemical was applied at the time of windrowing by mounting a sprayer on the tractor so that the material was deposited on the vegetation immediately in front of the cutting-bar of the mower.

RESULTS

Small Plot Trials

A summary of the data obtained from the small plot trials conducted in 1951 and 1952 is given in Table 1.

The seed yields obtained from alsike, ladino and birdsfoot trefoil were very low and significance could not be attached to any differences between them.

Germination values seemed quite variable but significant variations were not established.

Some of the treatments brought about an appreciable drying of the top growth. This was reflected in the dry matter figures obtained. From observation the most effective treatments were mixtures compounded of diesel oil or aromatic oil, with an additive of dinitro.

Table 2 gives the seed yields and moisture percentages obtained from the test conducted on alfalfa in 1953.

It will be observed that the seed yield figures obtained for treatments were not significant. The highest seed yields were secured from the untreated plots. The yields were lowest for the 8-day interval. There was no logical explanation for this. Differences between the treated and untreated plots were likely due to shattering. Significant figures for moisture content were established both for treatments and intervals. Endothal proved to be the most efficient of the treatments applied, having regard to reducing moisture content.

TABLE 2.—SEED YIELD AND MOISTURE CONTENT OF ALFALFA SUBJECTED TO CROP DESICCANT TREATMENTS

Treatment	4-Day interval		8-Day interval		11-Day interval		Mean	
	Seed yield	Moisture content	Seed yield	Moisture content	Seed yield	Moisture content	Seed yield	Moisture content
	lb.	per cent	lb.	per cent	lb.	per cent	lb.	per cent
1. Esso 500	63	45	36	28	57	32	52	35
2. Diesel oil	52	49	47	33	54	33	51	38
3. Endothal	58	39	49	19	56	22	54	27
4. Dinitro	63	40	36	23	54	27	51	30
5. Esso 5474B	65	44	48	31	61	30	58	35
6. Control	78	49	57	39	74	41	70	43
Mean—Treats. 1 to 5	60	43	43	27	56	29	53	33

L.S.D. (P. = .05)—Seed yield—between intervals—7.68.
Seed yield—between treatments—none.
Moisture content—between intervals—2.15 per cent.
Moisture content—between treatments—2.03 per cent.

C—Seed yield—intervals—29 per cent.
Seed yield—treatments—39 per cent.
Moisture content—intervals—13.2 per cent.
Moisture content—treatments—17.6 per cent.

On the basis of over-all mean figures of 70 lb. seed yield and 43 per cent moisture for the control, and 53 lb. seed yield and 33 per cent moisture for the treatments, it may be stated that desiccant treatment in this experiment reduced the moisture content by 23 per cent and reduced seed yield by 24 per cent.

Field Trials

The data in Table 3 show that the seed yields of alfalfa from the treated areas were markedly lower than those of the controls. This may have been due to extensive shattering. There was considerable variation in the seed germination figures obtained for alfalfa and red clover but it is doubtfu if significance can be drawn from this since the lowest germinations, in some cases, were shown by the treatments which were least effective in drying the foliage.

Combine losses due to incomplete threshing were estimated by sampling the tailings from the machine. Losses ranged as high as 23 per cent for alfalfa and 44 per cent for red clover. However, since sampling was done on only one replication, too much significance could not be attached to the difference between treatments. It is safe to say, however, that losses were not appreciably reduced by the desiccants used.

Perhaps the most significant result arising from the application of these materials was the effectiveness with which they reduced the moisture content of the herbage. In the case of alfalfa, significantly higher dry matter values were obtained from all treatments with the exception of diesel oil. The average dry matter of the plots on which desiccants were used was 64 per cent as compared with 51 per cent for the control. Approximately the same results were obtained on red clover with the best treatment having 74 per cent dry matter as compared to 57 per cent for the control.

TABLE 3.—SEED YIELDS, COMBINE LOSSES, PER CENT GERMINATION AND PER CENT DRY MATTER OF ALFALFA AND RED CLOVER SUBJECTED TO DESICCANT TREATMENTS

Treatments	Alfalfa					Red Clover				
	Seed yield	*Combine loss*		Per cent dry matter	Per cent germ.	*Combine loss*		Per cent germ.	Per cent dry matter
		Loss in tailings	Per cent loss in tailings			Loss in tailings	Per cent loss in tailings*		
	lb.	lb.				lb.			
1. Check	65	10.0	15.4	51	85	27.0	31.4	94	57
2. 2-4-D (amine)	14	1.6	11.3	61	79	29.5	34.4	88	66
3. Diesel oil	23	4.9	21.2	54	81	28.7	33.4	89	64
4. Mono-sodium cyanamid	19	0.7	3.5	66	73	34.4	40.1	88	67
5. Potassium cyanate	18	4.1	22.9	71	76	33.8	39.4	94	74
6. Esso 500	21	1.9	9.2	64	83	32.6	38.0	92	69
7. Dinitro	24	3.9	11.8	69	80	37.1	43.2	70	71
8. Pentachlorophenol	35	2.2	6.3	61	75	38.00	44.2	91	62
Mean	29	3.7	—	62	—	32.6	—	88	66
L.S.D. (P = .05)	None	—	—	10	—	—	—	—	—

* Based on estimated figure of 85.79 lb. per acre.

TABLE 4.—MOISTURE CONTENT, SEED YIELD AND SEED GERMINATION OF RED CLOVER PLOTS UNDER VARIOUS HARVESTING PROCEDURES

Treatments	Per cent moisture before treatment	Per cent moisture at time of harvest	Actual combine yields	Per cent germination
			lb.	
1. Dinitro plus diesel oil applied at time of windrowing	61	39	225	90
2. Windrowed—no desiccant	58	43	217	93
3. Dinitro plus diesel oil—"direct combined"	60	33	307	94
4. "Direct combined"—no desiccant	60	53	290	92

TABLE 5.—SEED YIELD, PER CENT DRY MATTER, GERMINATION AND THRESHABILITY OF ALSIKE TREATED WITH A DRYING CHEMICAL AT TIME OF WINDROWING

Treatment	Seed yield lb. per acre	Per cent dry matter		Seed germ. per cent	Threshability based on per cent recovery in first threshing		
		Before treatment	At harvest		a.m.	p.m.	av.
					lb.	lb.	lb.
1. Desiccant-dinitro plus disel oil	48	54	70	96	67	75	71
2. No desiccant	58	56	71	96	69	62	67
L.S.D. (P. = .05)	None	—	—	—	None	None	—

The data in Table 4 are derived from the test in which a treated and untreated windrow and a treated and untreated standing crop were compared.

The oil and dinitro application reduced the moisture content of the windrowed material from 61 per cent to 39 per cent, while that of the untreated windrow decreased from 58 per cent to 43 per cent. Similarly the treatment applied to the standing vegetation brought about a decrease in moisture from 60 to 33 per cent as opposed to a decrease of from 60 to 53 per cent in the untreated material.

Significantly lower yields were obtained from the windrowed areas than from those that were "direct combined". On the basis of a potential seed yield of 400 lb. per acre, determined by sampling, 54 per cent of the seed was harvested from the windrowed plots and 75 per cent from the "direct combined" plots.

A more elaborate field experiment designed to study the effectiveness of various treatments on alsike failed to give much useful data because of adverse weather conditions. However, part of the data obtained, summarized in Table 5, indicated that alsike seed harvesting was not facilitated by treatment.

DISCUSSION

On the basis of the tests detailed here it is not possible to draw definite conclusions as to the value of chemical desiccation of legume seed crops. The data, and general observations made during the past three years, do support the view that for eastern Ontario the practice is of doubtful value.

It was found that an appreciable reduction in moisture content of the legume herbage was brought about by the use of various chemicals and oils. Two to three pints of dinitro in 20 gallons of diesel oil to the acre was an effective treatment. However, there was no indication that such a treatment would ensure higher seed yields. Indeed under adverse conditions, where undue delay in harvest might occur after treatment, seed shattering might be very extensive. Extensive head and pod shattering occurred in crops of trefoil and alsike subjected to a heavy wind and rainstorm two days after the application of a desiccant.

Upright vegetation of the nature of that of alfalfa was cured better than that of dense, decumbent crops. Alsike became completely decumbent after treatment, making harvesting very difficult. In a matter of three to four days the recurrent growth in ladino lessened the beneficial effect of the treatment.

It was found that green pods affected by the chemical dried up quickly, and the seed in them was rendered inviable. In crops such as trefoil this might have detrimental affect on seed yield.

The passing of ground sprayers over the ripened seed fields caused a mechanical loss of about 10 per cent of the seed. This loss, coupled with a desiccant application cost of from $6.00 to $8.00 per acre, would make the use of crop desiccants uneconomical in areas where seed yields are generally low.

REFERENCES

1. Cooper, G. S., and W. G. Corns. Preharvest chemical top-killing of legume seed crops. Sci. Agr. 32 : 281-284. 1952.
2. Corns, W. G., and G. S. Cooper. Preharvest chemical top-killing of legume seed crops. 1. Preliminary studies with petroleum oils and potassium cyanate. Sci. Agr. 31 : 269-273. 1951.
3. Corns, W. G. Field experiments with herbicides—The use of contact herbicides as top killers for preharvest treatment of seed crops. Press Bull., Univ. of Alta., Vol. XXXVII, No. 1, p. 4. 1952.
4. Corns, W. G. The use of various contact herbicides for the preharvest top-killing of alfalfa, alsike clover and red clover. Agr.-Chem. Review, Vol. 1, No. 8, pp. 8-9. 1953.
5. Jones, L. G. Preharvest spraying to condition small seeded legumes for threshing. Down to Earth, Vol. 8, No. 1, pp. 2-4. 1953.
6. Medler, J. T. New chemical aids seed harvest. Crops and Soils, Vol. 5, No. 8, pp. 18, 19, and 30. 1953.
7. Slife, F. W. Preharvest spray and crop desiccants. Proc. North Cent. Weed Control Conf., pp. 91-92. 1952.

APPRAISAL OF CERTAIN METHODS FOR EVALUATION OF HAM QUALITY[1]

H. T. Fredeen, G. H. Bowman and J. G. Stothart[2]

Dominion Experimental Station, Lacombe, Alberta

[Received for publication September 2, 1954]

ABSTRACT

Specific gravity and certain planimeter areas of fat, lean and bone have been evaluated in terms of their utility for predicting the actual proportions of these three tissues in the ham. The simplest and the most reliable appraisal of ham quality was found to be the per cent area of lean in that ham surface exposed when this cut is removed from the carcass in the routine slaughter procedure. By this measure predictability of per cent lean in the ham was approximately 64 per cent. Tapering hams, carrying weight well down to the hock, were found to be leaner than those which appear plump through being well filled in the upper portion.

INTRODUCTION

The problem of ham quality is essentially one of lean content. A certain proportion of fat is desirable but excessive fatness necessitates trimming with subsequent loss to the industry. Terms such as "meaty", "plump" and "full" are commonly employed to describe hams but they do not account for the variability that exists in lean content nor can they, because of their purely descriptive nature, contribute consistently in a selective breeding program for improvement. There is also the possibility that such subjective classification may favour the fat hams rather than those with the optimum balance of fat and lean.

The purpose of this investigation was to study the relationships between several objective ham measurements and the actual fat, lean and bone content of the ham in an endeavour to establish an adequate measure of ham quality that could be conveniently employed in routine carcass evaluation.

MATERIALS AND METHODS

Hams used in this study were obtained from the hogs of several experimental breeding groups fed under standardized test conditions at the Lacombe Experimental Station. Also included, through the courtesy of the Production Service of the Canada Department of Agriculture, were 19 hams from Yorkshire hogs fed out at the Advanced Registry test station at Edmonton.

All hogs were slaughtered in Edmonton. After chilling for 24 hours the standard Advanced Registry cuts and measurements were made and one ham from each carcass was returned to the cooler. Shipments of hams to Lacombe were made twice weekly and here were held at 33° F. for a period not exceeding 24 hours prior to their measurement and dissection.

[1] Contribution from the Division of Animal Husbandry, Experimental Farms Services, Canada Department of Agriculture.

[2] Geneticist, Agricultural Research Officer and Senior Animal Husbandman, respectively, Dominion Experimental Station, Lacombe, Alta.

The data obtained included:

1. A tracing of the open face of the ham with fat, lean and bone clearly demarcated from which planimeter areas of all three were obtained.

2. Length of ham as measured from the forward edge of the aitch bone to the distal end of the shank (hock joint).

3. Air dry weight, weight in water and specific gravity computed as air dry weight divided by the weight loss in water.

4. A detailed tracing of the area exposed when the ham was cut at right angles to the axis of the length measurement and at a point 3 inches distal to the forward edge of the aitch bone. Planimeter areas of the constituent tissues were taken.

5. Complete dissection of the proximal and distal (shank) portions of the ham provided by the cross-section, and weights of the lean, fat and bone present in each.

All weights were recorded to the nearest gram on a Chatillon balance, measurements were taken to the nearest tenth of an inch and planimeter areas were computed in square inches to the second decimal. Percentage contribution of the constituent tissues to the total weights and total areas were computed for both portions of the ham as well as for the complete ham.

Data obtained were transposed to I.B.M. punch cards to facilitate computation.

RESULTS AND DISCUSSION

Means for several of the important ham characteristics are presented in Table 1. The F values for breed and sex differences were obtained by the analysis of variance recommended by Snedecor (1) for multiple classifications with disproportionate sub-class numbers and negligible interaction.

TABLE 1.—SUB-CLASS MEANS FOR CERTAIN HAM MEASUREMENTS

	Yorkshire		BW		BW × York		RW		F values* for differences between	
	M	F	M	F	M	F	M	F	Breed	Sex
No. of pigs	13	10	52	38	16	23	19	10	—	—
Sp. gravity (ham)	1.058	1.059	1.055	1.058	1.054	1.062	1.055	1.059	1.00	22.80
% lean of ham	57.7	60.4	57.3	59.3	56.9	61.2	55.6	58.0	4.98	45.76
% area lean (prox)	56.8	58.6	52.9	57.8	53.0	59.0	51.3	53.7	3.73	26.74
Wt. of ham (grams)	6969.5	7087.0	6700.7	6998.3	6879.8	7079.5	6397.0	6772.6	14.62	36.74
Ham length (in.)	13.65	13.76	13.12	13.33	13.29	13.49	13.05	13.33	8.96	9.95
% Shank of ham	54.8	55.6	53.2	54.2	53.0	54.8	51.2	52.8	11.08	15.53

* F values are highly significant if they exceed 3.91 for breed differences and 6.81 for sex differences.

TABLE 2.—GROSS CORRELATIONS BETWEEN MEASUREMENTS, ABSOLUTE WEIGH

NUMBERS AT THE TOP OF THE TABLE REFER TO

	1	2	3	4	5	6	7	8	9	10	11
1. Specific gravity											
2. Length of ham (in.)	.182										
3. Wt. of ham (gm.)	.272	.462									
4. Wt. lean of ham	.509	.462	.872								
5. Wt. fat of ham	−.575	−.179	.116	−.399							
6. Wt. bone of ham	.381	.639	.465	.490	−.317						
7. Wt. of shank end	.333	.600	.868	.837	−.086	.549					
8. Wt. lean of shank	.513	.566	.798	.916	−.377	.536	.939				
9. Wt. fat of shank	−.450	.074	.371	−.058	.778	−.075	.369	.041			
10. Wt. of proximal end	−.006	−.067	.569	.350	.375	.023	.086	.023	.132		
11. Wt. lean of prox.	.382	.123	.553	.780	−.312	.246	.361	.463	−.193	.709	
12. Wt. fat of prox.				−.538	.892	−.406		−.560	.411	.357	.45
13. Area lean in shank	.298	.268		.801	−.335	.339		.694	.024		.68
14. Area fat in shank	−.704	−.188		−.240	.632	−.200		−.266	.617		−.19
15. Area bone in shank				.021	−.030	.235		.085	−.054		−.08
16. Area lean in prox.				.697	−.405	.463		.582	−.148		.63
17. Area fat in prox.				−.539	.691	−.420		−.524	.398		−.37
18. Area bone in prox.				.260	−.306	.519		.313	−.185		.08
19. % lean of ham	.641	3.51	.494								
20. % fat of ham	−.664										
21. % shank of ham	.291										
22. % lean of shank											
23. % fat of shank											
24. % prox. of ham		−.495									
25. % lean of prox.			.421								
26. % fat of prox.											
27. % area lean in shank	.611			.611	−.677	.327		.572	−.477		.45
28. % area fat in shank	−.626			−.596	.677	−.346		−.565	.496		−.54
29. % area lean in prox.	.520		.421	.696	−.622	.484		.622	−.310		.56
30. % area fat in prox.	−.499			−.694	.633	−.497		−.625	.320		−.55

TAGE WEIGHTS AND PERCENTAGE AREAS OF THE COMPONENT TISSUES OF THE HAM.

IARACTERISTIC AS LISTED AT THE LEFT-HAND SIDE

	16	17	18	19	20	21	22	23	24	25	26	27	28	29
7														
2	−.578													
8	.251	−.222												
3	.652	−.701	.278											
0	−.655	.739	−.365	−.974										
				.439	−.488									
0	.554	−.633	.317	.926	−.904	.530								
9	−.522	.676	−.387	−.900	.932	−.458	−.959							
3	−.260	.405	−.258	−.420	.552	−.940	−.487	.460						
6	.653	−.666	.199	.933	−.905	.306	.729	−.722	−.275					
1	−.670	.713	−.300	−.938	.947	−.411	−.759	.777	.412	−.980				
				.768	−.771	.342	.752	−.764	−.299	.679	−.701			
				−.754	.772	−.341	−.748	.775	.352	−.642	.692	−.988		
				.797	−.788	.386	.673	−.696	−.364	.748	−.783	.642	−.640	
				−.764	.796	−.390	−.675	.738	.398	−.745	.787	−.643	.652	−.996

The superiority of the female in lean content of the ham is another manifestation of the widely reported sex difference in lean content of bacon carcasses. Females also have heavier, longer hams and these highly significant sex differences were consistent across the four breeding groups included in this study.

The lightest hams with the smallest lean content were from the "RW", an F_2 hybrid based on a Minnesota No. 1 and Landrace-Chester cross. The "BW", an F_3 hybrid based on a Berkshire and Landrace-Chester cross, gave results similar to the Yorkshire while the cross between the "BW" and the Yorkshire excelled in all measures of ham leanness.

The gross correlations of Table 2 show the associations between the various ham measurements. With 179 degrees of freedom, correlations of .147 and .192 are significant at the 5 per cent and 1 per cent levels of probability, respectively.

Certain correlations, i.e. between absolute weights and percentage weights, were not computed as they would have contributed little to the basic problems involved in this study. Moreover, the complete table will not be discussed but it is presented here for the benefit of those desiring the detailed information.

Weight of lean in the ham gave importantly large negative correlations with measures of fat in the ham, and importantly large positive correlations with all measures of lean. The correlations obtained were practically the same when the amount of lean was expressed as a percentage of the ham weight. The only important exceptions concern the percentage areas of fat and lean in the two ham tracings. These percentages were more highly associated with per cent lean of ham than with the absolute weight of lean.

Per cent area of lean in the proximal (open) face of the ham gave correlations of somewhat greater magnitude with most of the important measures of fat and lean than did per cent area of lean in the shank end (cross-section). This is of practical significance since obtaining the latter tracing would materially reduce the commercial value of this cut. Moreover, per cent area of lean in the open face of the ham gave correlations of considerably greater magnitude with the important measures of lean content than did the absolute area of lean in this tracing.

Percentage of weight in the proximal portion of the ham was negatively correlated with all measures of leanness of the ham and positively correlated with the measures of fatness. Conversely an increase in the percentage weight in the shank portion was accompanied by an increase in lean and a decrease in the fat of both portions of the ham. Length of ham obviously influenced the percentage distribution of weight in the proximal and shank portions by virtue of the manner in which this division was made. However, when length of ham was held constant by a partial correlation technique (1), the correlation between percentage weight of the proximal portion and per cent lean in the ham was $-.302$.

When visually comparing hams of the same length the weight distribution between the portions designated in this study as proximal and shank will influence the classification assigned. Thus a ham appearing well filled and plump in the upper portion will be appraised differently than a tapered ham that carries the fleshing more evenly distributed down to the

hock; but the relationships obtained in this study strongly suggest that the tapered ham is the leaner, more desirable type, and that the present ideal of a plump ham, well filled in the upper portion, actually favours the fatter hams. This finding emphasizes the need for a realignment of the visual appraisal standards.

Specific gravity was not as highly correlated with measures of ham leanness as was per cent area of lean in either ham section. The correlations of .64 and −.66 with per cent lean and per cent fat of the ham, respectively are also somewhat lower than those reported by Whiteman *et al.* (2). Since this measurement is not easily obtained, and since other measures appear to provide more adequate information on the lean content of the ham, it would appear to be of doubtful utility as a means of ham evaluation.

Bone content of the ham was positively associated with the measures of lean and negatively associated with the measures of fat made on both portions of the ham. Partial correlations suggest that a part of this association arises from the fact that long hams, which carry the greatest weight of bone, are also leaner hams. Per cent area of bone in the proximal tracing was highly correlated ($r = .515$) with per cent bone of the ham.

ACKNOWLEDGEMENT

Appreciation is expressed to J. G. Lefebvre and members of his staff in Production Service, Canada Department of Agriculture, for assistance in securing certain hams for this study and for clerical assistance in transcribing all the data to I.B.M. cards.

REFERENCES

1. Snedecor, Geo. W. Statistical methods, 4th ed. The Iowa State College Press, Ames, Iowa. 1948.
2. Whiteman, J. V., J. A. Whatley, and J. C. Hillier. A further investigation of specific gravity as a measure of pork carcass value. J. An. Sci. 12 : 4; 859-869. 1953.

RELATIONSHIPS BETWEEN CERTAIN MEASUREMENTS OF HAM AND CARCASS QUALITY[1]

H. T. Fredeen, G. H. Bowman and J. G. Stothart[2]

Dominion Experimental Station, Lacombe, Alberta

[Received for publication September 2, 1954]

ABSTRACT

Planimeter area of a cross-section of the loin muscle taken at the last rib was found to be highly associated with the per cent lean in the ham. This measure of carcass lean, when combined with the per cent area of lean in the proximal (open) face of the ham, accounted for 72 per cent of the variance in per cent lean in the ham. As an over-all measure of carcass lean, per cent area of lean in the proximal face of the ham was somewhat more reliable than loin area. Balance, a score presently assigned in Advanced Registry as a measure of the relative proportions of ham, middle and shoulder in the carcass, bore no relationship to ham leanness and accounted for only 13 per cent of the variance in ham weight.

INTRODUCTION

In the routine carcass evaluation that is a part of the Advanced Registry policy for swine in Canada, the only direct measure of ham is that embodied in the score for "balance". This score is based on the relative proportions of ham, middle and shoulder in the carcass.

Since the ham is one of the most valuable carcass cuts it is important that it constitute a reasonably high proportion of the carcass, and at the same time it is desirable to have an objective measure for appraising ham quality in order to promote genetic improvement. A score based on weight alone is insufficient to account for the variation of interior quality as indicated by relative lean and fat content. Moreover, systems of scoring which depend on visual evaluation of ham quality are not so accurate nor so widely adaptable as would seem to be necessary to contribute consistently in a selective breeding program.

In a previous paper (2) the authors have discussed the utility of several objective ham measurements for evaluating the lean content of hams. This present study is concerned with the relationships existing between characteristics of the ham and those of carcass, with the view to determining the combination of simple measurements which will best evaluate carcass quality.

MATERIALS AND METHODS

The carcasses of 181 hogs were utilized in this study. These represented several experimental breeding groups fed under standardized test conditions at the Lacombe Experimental Station, together with 19 Yorkshire hogs fed out at the Advanced Registry test station at Edmonton. The designation "BW" in the following table indicates F_3 hybrids from a foundation of Landrace-Chester and Berkshire being investigated as a potential bacon breed at Lacombe. The BW × York are first crosses between this foundation and the Yorkshire, while the "RW's" are F_2 hybrids between the Landrace-Chester and the Minnesota No. 1.

[1] Contribution from the Division of Animal Husbandry, Experimental Farms Services, Canada Department of Agriculture.

[2] Geneticist, Agricultural Research Officer and Senior Animal Husbandman, respectively, Dominion Experimental Station, Lacombe, Alta.

All hogs were slaughtered when they reached a live weight of 197 plus or minus 3 pounds. After chilling for 24 hours, certain carcass measurements were taken according to standard Advanced Registry procedure (1). At the same time one ham was removed from each carcass to permit the detailed measurements. These measurements and the complete results of this ham study have been reported in a previous paper (2).

All data were transposed to I.B.M. cards to permit simultaneous computation of all desired correlations.

RESULTS AND DISCUSSION

Means for the important carcass measurements and scores and F values for breed and sex differences are given in Table 1. The latter were obtained from the analysis of variance recommended by Snedecor (3) for multiple classifications with disproportionate sub-class numbers and negligible interaction.

TABLE 1.—SUB-CLASS MEANS FOR CARCASS MEASUREMENTS AND SCORES

	Yorkshire		BW		BW × York		RW		F values* for differences between	
	M	F	M	F	M	F	M	F	Breed	Sex
No. of pigs	13	10	52	38	16	23	19	10	—	—
Length (in.)	30.77	30.88	29.86	30.09	30.23	30.22	30.64	30.78	13.63	1.91
Loin area (sq. in)	3.49	3.81	3.41	3.99	3.55	4.17	3.04	3.67	9.44	86.17
Shoulder fat. (in.)	1.88	1.83	1.89	1.84	1.86	1.78	1.80	1.78	2.67	6.11
Back fat (in.)	.95	.85	1.05	.97	.97	.90	1.00	.92	7.72	18.91
Loin fat (in.)	1.40	1.35	1.44	1.38	1.46	1.36	1.48	1.42	1.07	8.75
Belly score	14.8	18.0	16.5	18.2	16.2	18.3	17.7	19.0	1.80	14.44
Balance	6.3	6.8	6.7	7.2	6.9	7.1	7.1	8.4	4.07	8.76
Total score	71.0	80.4	66.4	78.0	68.1	80.6	67.7	81.2	.80	46.51
Age	198.0	190.5	195.6	198.1	188.6	188.4	182.4	182.9	4.87	15.10

* F values are highly significant if they exceed 3.91 for breed differences and 6.81 for sex differences.

Breed differences in loin area (planimeter area of the cross section of the longissimus dorsi taken at the last rib) were highly significant with the BW-York hybrids producing the greatest and the RW the least amount of lean. In this respect the RW shows the weakness evident in the pure Minnesota No. 1 parent stock utilized in its foundation†.

The females of all breeding groups show superiority in leanness of carcass. This is culminated by the highly significant differences in total score and is in agreement with findings reported for the Canadian Yorkshire (1).

† Unpublished data from the Annual Report of the Experimental Station, Lacombe, Alta. 1952.

TABLE 2.—GROSS CORRELATIONS BETWEEN NINE CARCASS MEASUREMENTS AND SCORES AND LEAN, FAT AND BONE CONTENT OF THE HAM

	Carcass length	Shoulder fat	Back fat	Loin fat	Loin area	Belly score	Total score	Balance	Age
Specific gravity	.118	−.222	−.387	−.401	.490	.206	.495	.019	.224
Ham length	.269	−.192	−.362	−.340	.264	.176	.397	.082	.173
Ham weight	.188	−.198	−.221	−.252	.661	.049	.304	.360	.119
Weight lean in ham	−.095	−.323	−.393	−.396	.846	.215	.541	.260	.156
Weight fat in ham	−.250	.291	.408	.371	−.410	−.321	−.540	.171	−.078
Weight bone in ham	.326	−.241	−.450	−.417	.257	.094	.420	.001	.039
Weight of shank end	−.045	−.226	−.350	−.414	.624	.135	.438	.251	.170
Weight lean in shank	.021	−.290	−.436	−.443	.743	.207	.554	.224	.184
Weight fat in shank	−.288	.152	.222	.044	−.127	−.160	−.252	.159	.019
Weight bone in shank	.305	−.230	−.416	−.408	.224	.092	.394	.004	.040
Weight of proximal end	−.304	−.023	.136	.181	.292	−.126	−.116	.306	−.044
Weight lean in prox.	−.242	−.262	−.188	−.183	.711	.151	.332	.220	.057
Weight fat in prox.	−.156	.314	.464	.506	−.503	−.351	−.602	−.134	.127
Weight bone in prox.	.321	−.230	−.450	−.382	.278	.087	.412	−.003	.032
Total area shank end	−.197	−.134	−.045	−.123	.488	.072	.201	.257	−.027
Area lean in shank	−.120	−.249	−.210	−.263	.653	.166	.392	.178	.056
Area fat in shank	−.188	.210	.314	.250	−.222	−.170	−.333	.181	−.158
Area bone in shank	.202	−.256	−.246	−.144	−.032	.099	.183	.118	.017
Total area of prox. end	−.192	.054	.078	.235	.229	−.085	−.072	.239	−.101
Area lean in prox.	−.094	−.250	−.307	−.326	.610	.204	.366	.074	.038
Area fat in prox.	−.084	.336	.434	.483	−.483	−.312	−.493	.143	−.135
Area bone in pox.	.286	−.062	−.356	−.196	.196	.043	.312	−.065	−.057
% lean of ham	.021	−.356	−.451	−.420	.794	.320	.630	.095	.149
% fat of ham	−.124	.375	.508	.464	−.723	−.325	−.658	−.031	−.137
% shank of ham	.138	−.182	−.380	−.460	.368	.189	.430	.036	.170
% lean of shank	.122	−.320	−.458	−.364	.736	.271	.604	.131	.153
% fat of shank	−.233	.335	.498	.379	−.644	−.272	−.616	−.108	−.122
% prox. of ham	−.080	.193	.380	.459	−.348	−.178	−.429	.026	−.151
% lean of prox.	−.079	−.346	−.376	−.406	.741	.323	.567	.087	.119
% fat of prox.	−.017	.364	.449	.473	−.442	−.332	−.623	−.061	−.122
% bone of prox.	.454	−.184	−.464	−.427	.095	.138	.423	−.197	.056
% area lean of shank	.078	−.282	−.346	−.326	.524	.226	.468	−.058	.152
% area fat of shank	−.095	.307	.372	.341	−.542	−.234	−.482	.016	−.157
% area lean of prox.	−.010	−.338	−.408	−.452	.615	.298	.486	−.043	.103
% area fat of prox.	.003	.340	.422	.459	−.612	−.297	−.494	.017	−.099
Shoulder fat	−.133								
Back fat	−.277	.472							
Loin fat	−.105	.508	.632						
Loin area	−.165	−.215	−.322	−.314					
Belly score	.045	−.233	−.267	−.142	.283				
Total score	.429	−.517	−.273	−.631	.543	.535			
Balance	−.054	−.190	−.111	−.012	.204	.066	.216		
Age	−.110	.004	−.074	−.201	.176	.145	.200	.096	

Gross correlations between the carcass measurements and the detailed measurements made on the ham are presented in Table 2. With 179 degrees of freedom, correlations of .147 and .192 are significant at the 5 per cent and 1 per cent levels of probability respectively. While only the more important of these correlations will be discussed, the complete table is presented for reference purposes.

Planimeter area of the loin muscle (cross-section taken at the last rib) is used in Advanced Registry as a standard for comparing relative leanness of carcasses. Its utility for this purpose is indicated by the magnitude of the correlations it bears with all the measures of lean and fat in the ham.

This is further emphasized by the fact that the correlation of .794 between per cent lean of ham and loin area is practically the same as the .797 reported (2) between per cent lean of ham and per cent area of lean in the proximal (open) face of the ham.

The three back fat measurements were highly associated positively with the fat and negatively with the lean measurements made on the ham. In fact the three correlations of −.338, −.408 and −.452 between shoulder, back and loin fat, respectively and per cent area of lean in the proximal portion of the ham are larger than the −.215, −.322 and −.314 between these same fat measurements and loin area. This would indicate that the former measure may be more highly indicative of general carcass leanness than is loin area. The highly significant negative correlations between the back fat measurements and ham length, which suggests that the longer hams come from leaner carcasses, may explain at least part of the negative correlations that exist between these same fat measurements and weight of bone in the ham.

Loin area gave the highly significant correlation of −.348 with per cent weight in the proximal (upper) portion of the ham. All back fat measurements gave highly significant positive correlations with the same cut. These relationships provide further evidence that hams well filled and plump in the upper portion actually come from the fatter carcasses (2).

All correlations between carcass length and bone measurements of the ham were positive and highly significant. At least part of these associations may be explained by the correlation of .269 between carcass length and ham length but the relationship of the bone areas in the two ham sections with carcass length indicated that hams with the greatest bone were associated with the longer carcasses.

The fact that slaughtering is done at a standard live weight would tend to cause the longer carcasses to be leaner than their shorter contemporaries. This introduces some automaticity between certain of the correlations reported here but the degree of this automaticity is impossible to evaluate from this study.

The magnitude of the correlations between total score and all measures of fat, lean and bone of the ham is indicative of the utility of this composite measure of carcass quality. Belly score, which evaluates an optimum balance of lean and fat in the bacon rasher, was correlated positively with all measures of lean in ham and carcass and negatively with all measures of fat.

Balance showed no evidence of being a useful measure of ham quality. Its correlation of .260 with weight of lean in the ham is merely a reflection of the part played by ham weight in determining score for balance. This is confirmed by the small and non-significant correlation of .095 between balance and per cent lean of the ham. Moreover, the correlation of .360 between balance and ham weight indicates that this score accounts for only 13 per cent (r^2) of the variance existing in ham weight.

Age of the pig at slaughter did not appear to bear an important association with any of the ham or carcass measurements. Most of them, including those with bone measurements of the ham, differed little from zero.

Correlations between the various carcass measurements were essentially the same as those previously reported for the Canadian Yorkshire (1).

Certain of the more important correlations reported in this and the previous paper (2) were recomputed on an intra-breed, intra-sex basis to discount any portion of the gross correlations that might result automatically from breed or sex differences. These are presented in Table 3.

TABLE 3.—INTRA SUB-GROUP (BREED AND SEX) CORRELATIONS BETWEEN FOUR IMPORTANT HAM MEASUREMENTS AND FIVE CARCASS MEASUREMENTS AND SCORES

	% lean of ham	% fat of ham	% area lean of prox. end	% area fat of prox. end	Loin area	Shoulder fat	Back fat	Loin fat	Belly score	Balance
Weight of ham	.309	—	.241	—	.504	−.212	−.057	−.139	.010	.363
% lean of ham		−.970	.757	−.710	.718	−.355	−.376	−.342	.288	−.025
% fat of ham			−.744	.752	−.642	.377	.429	.326	−.313	−.080
% area lean of prox.				−.995	.509	−.338	−.330	−.387	.283	−.050
% area fat of prox.					−.504	.341	.341	.394	−.283	.032
Loin area						−.186	−.204	−.210	.236	.156
Shoulder fat							.449	.521	−.178	−.199
Back fat								.633	−.236	−.105
Loin fat									−.112	−.045
Belly score										−.048

The correlations reported here differ but slightly from the corresponding gross correlations. This close agreement indicates that differences between sub-class means did not contribute importantly to the degree of association between these characteristics.

Utilizing these correlations the predictability of per cent lean of the ham is approximately 51 per cent from loin area and 57 per cent from per cent area of lean in the proximal end. Combination of these two measures of lean by a multiple correlation technique (3) raised the predictability to 72 per cent (the square of the multiple correlation coefficient 0.850).

Correlations between per cent area of lean in the proximal end and the three measurements of back fat were of considerably greater magnitude than those between loin area and the same fat measurements. This suggests that the inclusion of a measure of ham leanness in routine carcass evaluation would serve the dual purpose of providing an objective measure of ham quality and of placing greater emphasis on the quantity of lean in the entire carcass.

ACKNOWLEDGEMENT

Appreciation is expressed to J. G. Lefebvre and members of his staff in Production Service, Canada Department of Agriculture, for clerical assistance in transcribing all the data to I.B.M. cards.

REFERENCES

1. Fredeen, H. T. Genetic aspects of Canadian bacon production. Pub. 889, Canada Dept. of Agr., Ottawa. 1953.
2. Fredeen, H. T., G. H. Bowman, and J. G. Stothart. Appraisal of certain methods for evaluation of ham quality. Can. J. of Agr. Sci. 35 : 91-94. 1955.
3. Snedecor, Geo. W. Statistical methods, 4th ed. The Iowa State College Press, Ames, Iowa. 1948.

ERRATA

In the paper "Rapeseed oil meal in broiler rations with observations on the nature and control of its metabolic inhibitors", by Dorothy S. Dow and C. E. Allen, published in the November-December, 1954, issue (Vol. 34, No. 6), pp. 607-613, the following errors appeared:

TABLE 2: Trial 2, first line, for "4658" read "4558".
Trial 3, for "18% rape" read "15% rape".

TABLE 3: Trial 1, first line under I_2, for "2" read "3".

TABLE 4: Superscript figure "4" is missing from last footnote.

ERRATUM

In the paper "Zinc for potatoes in Nova Scotia" by D. Chisholm and C. R. MacEachern, published in the November-December, 1954, issue (Vol. 34, No. 6.) on page 598, 11th line from bottom, read "per 100 gal.", not "per gal."